Appendix D: Climate impacts and adaptation actions for whitebark pine

The Washington-British Columbia Transboundary Climate-Connectivity Project engaged science-management partnerships to identify potential climate impacts on wildlife habitat connectivity and adaptation actions for addressing these impacts in the transboundary region of Washington and British Columbia.[i] Project partners focused their assessment on a suite of case study species, a vegetation system, and a region chosen for their shared priority status among project partners, representation of diverse habitat types and climate sensitivities, and data availability. This appendix describes potential climate impacts and adaptation actions identified for the Whitebark pine (*Pinus albicaulis*).

Figure D.1. Whitebark pine.

Whitebark pine is a montane conifer found in upper subalpine and treeline forests of western North America.[2] The species currently faces a combination of severe threats from the introduced white pine blister rust (*Cronartium ribicola*); large outbreaks of mountain pine beetle (*Dendroctonus ponderosae*); and wildfire suppression, which has limited seedling establishment, survival, and growth, while facilitating subalpine encroachment of other tree species that were historically limited by natural fire regimes.[3] In the transboundary region of Washington and British Columbia, scattered populations of whitebark pine are found in eastern Washington and southern British Columbia, with more extensive populations along the eastern slopes of the Cascades and Coast Ranges.[2] Dispersal of whitebark pine is facilitated by wind and birds, which transport pollen and seeds, respectively. Seed dispersal depends almost entirely on Clark's nutcracker (*Nucifraga columbiana*).[3]

Future climate change may present additional challenges and needs for whitebark pine connectivity.[4-5] First, climate change may impact whitebark pine core habitat and dispersal habitat in ways that may make them more or less permeable to movement. Second, existing whitebark pine core habitat and dispersal habitat may be distributed on the landscape in ways that make them more or less able to accommodate climate-driven shifts in whitebark pine distributions. For such reasons, connectivity enhancement has become the most frequently recommended climate adaptation strategy for biodiversity conservation.[6] However, little work has been done to translate this broad strategy into specific, on-the-ground actions. Furthermore, to our knowledge, no previous work has identified specific climate impacts or adaptation responses for whitebark pine habitat connectivity. To address these needs, we describe here a novel effort to identify and address potential climate impacts on whitebark pine habitat connectivity in the transboundary region of Washington and British Columbia.

Potential climate impacts on habitat connectivity

To identify potential climate impacts on transboundary whitebark pine connectivity, project partners created a conceptual model that identifies the key landscape features and processes expected to influence whitebark pine connectivity, which of those are expected to be influenced by climate, and how (Appendix D.2). Simplifying complex ecological systems in such a way can make it easier to identify

[i] This report is Appendix D of the Washington-British Columbia Transboundary Climate-Connectivity Project; for more information about the project's rationale, partners, methods, and results, see Krosby et al. (2016).[1]

specific climate impacts and adaptation actions. For this reason, conceptual models have been promoted as useful adaptation tools, and have been applied in a variety of other systems.[7] The whitebark pine conceptual model was developed using peer-reviewed articles and reports, project participant expertise, and review by species experts. That said, the resulting model is intentionally simplified, and should not be interpreted to represent a comprehensive assessment of the full suite of landscape features and processes contributing to whitebark pine habitat connectivity.

Project participants used conceptual models in conjunction with maps of projected future changes in species distributions, vegetation communities, and relevant climate variables to identify potential impacts on whitebark pine connectivity. Because a key project goal was to increase practitioner partners' capacity to access, interpret, and apply existing climate and connectivity models to their decision-making, we relied on a few primary datasets that are freely available, span all or part of the transboundary region, and reflect the expertise of project science partners. These sources include habitat connectivity models produced by the Washington Connected Landscapes Project,[8,9] future climate projections from the Integrated Scenarios of the Pacific Northwest Environment[10] and the Pacific Climate Impacts Consortium's Regional Analysis Tool,[11] and models of projected range shifts and vegetation change produced as part of the Pacific Northwest Climate Change Vulnerability Assessment.[12]

Key impacts on transboundary whitebark pine connectivity identified via this approach include changes in areas of climatic suitability for whitebark pine, declines in the amount and duration of snowpack, changes in disturbance regimes, and changes in seed dispersal.

Changes in areas of climatic suitability

Climate change may affect whitebark pine habitat connectivity by changing the extent and location of areas of climatic suitability for whitebark pine; this may render some existing core habitat areas and corridors unsuitable for whitebark pine, and/or create new areas of suitability. Climatic niche models (CNMs) provide estimates of species' current and projected future areas of climatic suitability, and are available for the whitebark pine for the 2080s based on two CMIP3 Global Circulation Models (GCMs): CGCM3.1(T47) and UKMO-HadCM3 (Appendix D.3).[ii] Both models use the A2 (high) carbon emissions scenario.[iii] CNMs for whitebark pine were developed using the historical distribution of whitebark pine, rather than the current observed distribution.

There is strong agreement between models that lower elevations and latitudes in the transboundary region will become less climatically suitable for whitebark pine, with range contractions projected across many of these areas. Mid-elevations within the current range may or may not lose climatic suitability depending on the climate model used. There is strong agreement that high elevations on the east side of

[ii] CGCM3.1(T47) and UKMO-HadCM3 are two different Global Circulation Models (GCMs) used to project future changes in climate. The UKMO-HadCM3 model projects a much hotter and drier summer, while the CGCM3.1(T47) projects greater precipitation increases in spring, summer and fall. For these reasons, the UKMO-HadCM3 could be considered a "hot-dry" future, while the CGCM3.1(T47) could be considered a "warm-wet" future within the Pacific Northwest.

[iii] Emissions scenarios were developed by climate modeling centers for use in modeling global and regional climate-related effects. A2 is a high, "business as usual" scenario in which emissions of greenhouse gases continue to rise until the end of the 21st century, and atmospheric CO_2 concentrations more than triple by 2100 relative to pre-industrial levels.

the Cascades, in the Coast Range, and in the Purcell and North Columbia Mountains are projected to remain climatically suitable. However, other than in the North Columbia Mountains, remaining areas of suitable habitat are projected to be smaller and more fragmented. The extent of suitable habitat loss and fragmentation is most extensive in the Cascades and at the southern end of the Purcell Mountains, though this is somewhat dependent on the climate model used. Note that because whitebark pine does not currently occupy many of the areas projected to decline in climatic suitability (Appendix D.3), CNMs likely suggest more extensive range loss and fragmentation than is likely to occur.

Declining amount and duration of snowpack

Projected declines in the amount and duration of snowpack (Appendix D.6: Spring (April 1st) Snowpack; Snow Season Length) may affect whitebark pine connectivity by promoting encroachment of low-elevation tree species into areas previously excluded by snowpack.[13,14] Snowpack also provides soil moisture in the summer months as the snow melts (Appendix D.6; Summer Soil Moisture), which is important for tree growth and seedling establishment.[15] Snowpack also provides protection from damaging ice particles in high winds.[16]

Changes in disturbance regimes

Climate change may affect whitebark pine connectivity by increasing the frequency and severity of summer drought (Appendix D.6: Water Deficit, July – September; Soil Moisture, July - September), increasing the risk of wildfires (Appendix D.6: Days with High Fire Risk), and influencing pest and pathogen dynamics (Appendix D.5). Though whitebark pine is adapted to dry summer conditions, extreme drought could limit seedling establishment and growth.[3] A longer fire season and increases in area burned could also affect whitebark pine,[17] given that whitebark pine has adapted to a long fire return interval (50 to 500 years).[18,19] Moisture stress and fire can increase tree mortality and bark beetle outbreaks, which can further increase the chances of large, high-intensity fires. In Washington State, the probability of mountain pine beetle survival is projected to decline at lower elevations, but to increase at higher elevations (Appendix D.5), which may affect high-elevation whitebark pine populations that are beyond the beetle's current distribution.

Changes in whitebark pine seed dispersal

Whitebark pine regeneration can be facilitated over large areas by Clark's nutcrackers, which are able to cache seeds long distances (8 km or more) from seed sources.[19,20] Clark's nutcracker is considered particularly sensitive to climate change because of its close dependence on whitebark pine and other conifers with large seeds. Changes in the abundance and distribution of large-seeded conifers may lead to dispersal barriers for the Clark's nutcracker because survival probability declines if nutcrackers are forced to disperse over very large distances (>500 km) without access to seed sources.[21] In addition, small stands of whitebark pine may not offer a sufficient density of seeds to attract Clark's nutcrackers.[2] Consequently, smaller and more isolated whitebark pine stands may be at risk of losing dispersal services, resulting in further stand loss and isolation. However, projected increases in wildfire (Appendix D.6: Days with High Fire Risk) may increase the availability of the open habitats preferred by Clark's nutcracker for seed caching,[3] and thus improve dispersal of whitebark pine.

Adaptation responses

After identifying potential climate impacts on whitebark pine connectivity, project participants used conceptual models to identify which relevant landscape features or processes could be affected by management activities, and subsequently what actions could be taken to address projected climate impacts (Appendix D.2). Key adaptation actions identified by this approach fall under three main categories: those that address potential climate impacts on whitebark pine habitat connectivity, those that address novel habitat connectivity needs for promoting climate-induced shifts in whitebark pine distributions, and those that identify spatial priorities for implementation.

Addressing climate impacts on whitebark pine habitat connectivity

Actions to address the potential for whitebark pine populations to become increasingly isolated and fragmented include:

- Developing a planting plan that evaluates and potentially includes genotypes adapted to projected future climatic conditions. The planting plan could be used to benefit human-mediated dispersal efforts, which could enhance connectivity among isolated stands of whitebark pine. Whenever possible, managers should follow best planting practices, including using endophytes and disease- and pest-resistant trees.
- Preventing encroachment of tree species that are encroaching on whitebark pine habitat due to fire suppression policies. This could be accomplished by mechanically removing invading trees or using prescribed burns to reduce tree recruitment. Note that this may be ineffective or undesirable in the long term or over large scales, due to its labor intensity and the risks associated with prescribed burns, as well as the need for lower elevation habitats to shift upward to adapt to change. Therefore, consider implementing only within priority whitebark pine populations (e.g., those large enough to attract Clark's nutcrackers and act as a seed source, and/or that comprise important stepping stones among isolated stands).
- Monitoring and responding to changes in whitebark pine stands that may affect connectivity (e.g., detecting loss of highly central stands, replanting if conditions remain suitable for whitebark pine).

Actions to address the potential for climate change to impact connectivity through disturbance regime shifts include:

- Applying thinning or prescribed burns to reduce the risk of catastrophic wildfires and pest outbreaks that could negatively impact whitebark pine.
- Identifying and protecting whitebark pine stands that are likely to be climate-resilient or act as key habitat connectivity links among isolated populations. This could help managers target management actions to minimize the risks of damage from fire or insects to these stands.

Actions to address the potential for climate change to impact whitepark pine seed dispersal:

- Identifying and protecting whitebark pine stands that are large enough to attract Clark's nutcrackers and serve as a seed source.
- Identifying and protecting whitebark pine stands that could serve as links or stepping stones for Clark's nutcrackers moving among larger populations of whitebark pine.

Enhancing connectivity to facilitate range shifts

Actions that may help whitebark pine adjust its range to track shifts in areas of climatic suitability include:

- Maintaining and restoring corridors that span elevation and climatic gradients (Appendix D.1),[9] to promote whitebark pine dispersal into cooler habitats that may remain or become climatically suitable.

- Planting whitebark pine to establish stands in unoccupied areas of suitable habitat, particularly those that are projected to remain climatically suitable, or that could provide stepping stones to areas of projected stability or expansion (Appendix D.3).

Spatial priorities for implementation

Spatial priorities for implementation of the adaptation actions described above include:

- Areas likely to remain or become climatically suitable for whitebark pine (Appendix D.3), particularly those within the Cascade Range and Purcell mountains, which may act as refugia among areas of widespread future habitat loss.
- Landscape integrity and climate-gradient corridors (Appendix C.1).[8-9] Landscape linkages that are in good natural condition (i.e., landscape integrity corridors) and that span climate gradients (i.e., climate-gradient corridors) may help promote seed dispersal among existing whitebark pine populations and future areas of climatic suitability.

Policy considerations

Land use planning and management

Actions for addressing climate impacts on whitebark pine habitat connectivity through land use planning and management include:

- Limiting the development of forestry activities in high elevation areas, particularly those projected to remain climatically suitable for whitebark pine.
- Reviewing and implementing existing guidance and plans relating to whitebark pine habitat management. Evaluate existing recommendations for opportunities to address climate impacts.
- Coordinating stewardship and management activities with provincial and local governments, NGOs, tribes and First Nations, and especially with private landowners.
- Be prepared to address and/or modify the legal context for whitebark pine management. In the United States, whitebark pine is a candidate for the Endangered Species Act; climate impacts on whitebark pine connectivity should be addressed in critical habitat designations or recovery plans.

Research needs

Future research that could help inform whitebark pine habitat connectivity conservation under climate change includes:

- Developing fine-scale, transboundary maps of the current distribution of whitebark pine.[22] This would help to inform interpretation and use of whitebark pine CNMs (e.g., some high elevation areas may be currently classified as “stable” when in fact they are “expansion” areas), and direct implementation of adaptation actions described above.
- Evaluating the extent to which landscape features (and whitebark pine features such as basal area) influence Clark’s nutcracker movement and seed dispersal. This could help identify actions to improve dispersal.
- Identifying climate resilient whitebark pine core habitat areas. Overlay climatic niche models (Appendix D.3) with projected changes in vegetation (Appendix D.4) with) and climate variables (Appendix D.6). Areas where suitable habitat is retained and changes in climatic variables are relatively modest may be most likely to support future whitebark pine populations. These

climate-resilient habitat areas may be used as priority areas for the adaptation actions described above.

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Glossary of Terms

Assisted migration – Species and populations are deliberately planted or transported to new suitable habitat locations, typically in response to declines in historic habitat quality resulting from rapid environmental change, principally climate change.

Centrality — Refers to a group of landscape metrics that rank the importance of habitat patches or linkages in providing movement across an entire network, i.e., as "gatekeepers" of flow across a landscape.[iv]

Connectivity — Most commonly defined as the degree to which the landscape facilitates or impedes movement among resource patches.[v] Can be important for maintaining ecological, population-level, or evolutionary processes.

Core Areas — Large blocks (10,000+ acres) of contiguous lands with relatively high landscape permeability.

Corridor — Refers to modeled movement routes or physical linear features on the landscape (e.g., continuous strips of riparian vegetation or transportation routes). In this document, the term "corridor" is most often used in the context of modeled least-cost corridors, i.e., the most efficient movement pathways for wildlife and ecological processes that connect HCAs or core areas. These are areas predicted to be important for migration, dispersal, or gene flow, or for shifting ranges in response to climate change and other factors affecting the distribution of habitat.

Desiccation – Extreme water deprivation, or process of extreme drying.

Dispersal — Relatively permanent movement of an individual from an area, such as movement of a juvenile away from its place of birth.

Fracture Zone — An area of reduced permeability between core areas. Most fracture zones need significant restoration to function as reliable linkages. Portions of a fracture zone may be potential linkage zones.

Habitat Connectivity — See Connectivity.

Landscape Connectivity — See Connectivity.

Permeability — The ability of a landscape to support movement of plants, animals, or processes.

[iv] Carroll, C. 2010. Connectivity analysis toolkit user manual. Version 1.1. Klamath Center for Conservation Research, Orleans, California. Available at www.connectivitytools.org (accessed January 2016).

[v] Taylor, P. D., L. Fahrig, K. Henein, and G. Merriam. 1993. Connectivity is a vital element of landscape structure. *Oikos* 68: 571-573.

Pinch point — Portion of the landscape where movement is funneled through a narrow area. Pinch points can make linkages vulnerable to further habitat loss because the loss of a small area can sever the linkage entirely. Synonyms are bottleneck and choke point.

Refugia – Geographical areas where a population can survive through periods of unfavorable environmental conditions (e.g., climate-related effects).

Thermal barriers – Water temperatures warm enough to prevent migration of a given fish species. These barriers can prevent or delay spawning for migrating salmonids.

Appendices D.1-6

Appendices include all materials used to identify potential climate impacts on habitat connectivity for case study species, vegetation systems, and regions. For whitebark pine, these materials include:

Appendix D.1. Habitat connectivity models
Appendix D.2. Conceptual model of habitat connectivity
Appendix D.3. Climatic niche models
Appendix D.4. Projected changes in vegetation communities
Appendix D.5. Projected changes in probability of mountain pine beetle survival
Appendix D.6. Projected changes in relevant climatic variables

All maps included in these appendices are derived from a few primary datasets, chosen because they are freely available, span all or part of the transboundary region, and reflect the expertise of project science partners. These sources include habitat connectivity models produced by the Washington Connected Landscapes Project,[8,9] future climate projections from the Integrated Scenarios of the Pacific Northwest Environment[10] and the Pacific Climate Impacts Consortium's Regional Analysis Tool,[11] and models of projected range shifts and vegetation change produced as part of the Pacific Northwest Climate Change Vulnerability Assessment.[12]

All maps are provided at three geographic extents corresponding to the distinct geographies of the three project partnerships (Fig. D.2):

i. **Okanagan Nation Territory**, the assessment area for project partners: Okanagan Nation Alliance and its member bands and tribes, including Colville Confederated Tribes.
ii. **The Okanagan-Kettle Region**, the assessment area for project partners: Transboundary Connectivity Working Group (i.e., the Washington Habitat Connectivity Working Group and its BC partners).
iii. **The Washington-British Columbia Transboundary Region**, the assessment area for project partners: BC Parks; BC Forests, Lands, and Natural Resource Operations; US Forest Service; and US National Park Service.

All project reports, data layers, and associated metadata are freely available online at: https://nplcc.databasin.org/galleries/5a3a424b36ba4b63b10b8170ea0c915e

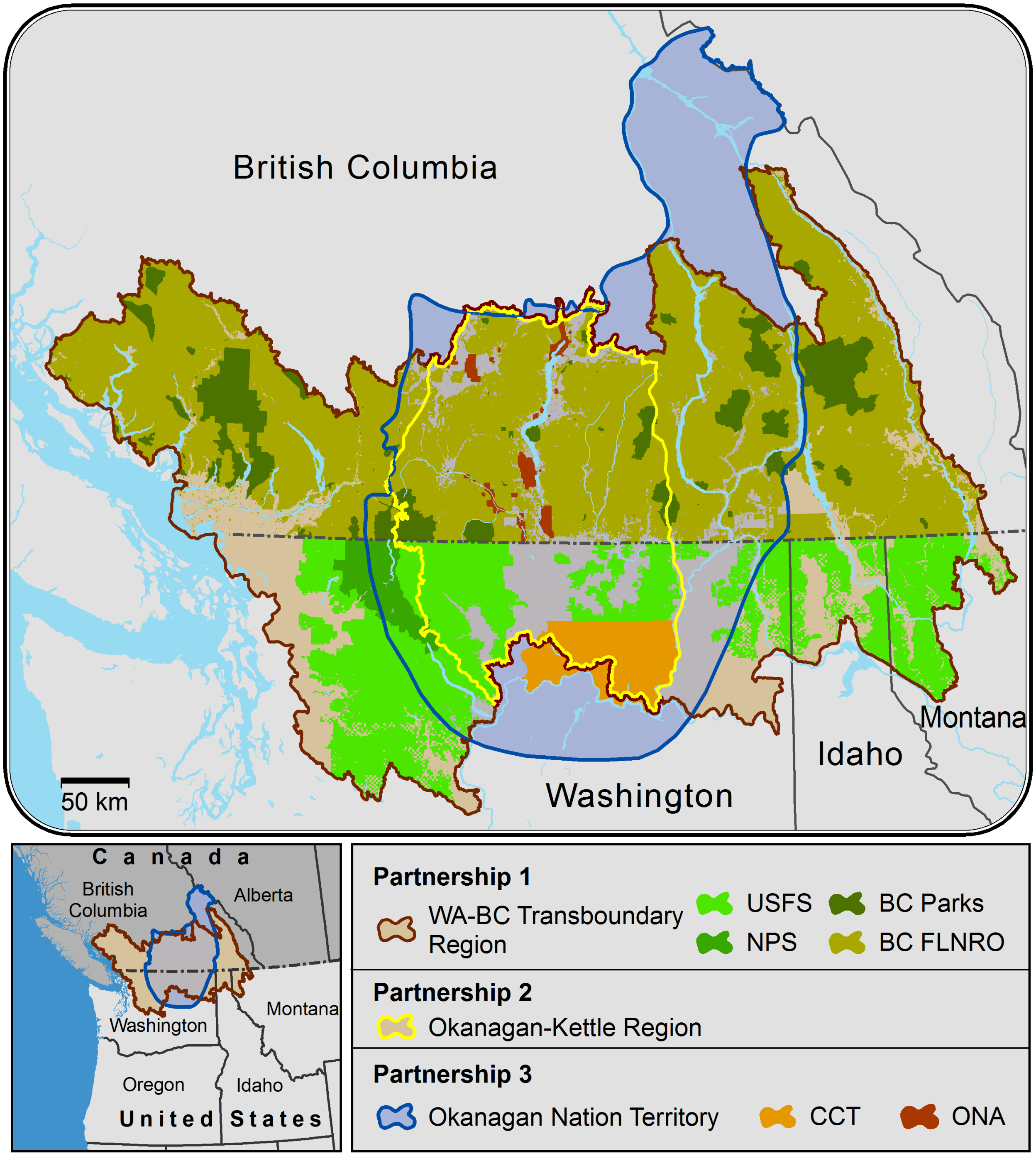


Figure D.2. Project partners and assessment areas.

Appendix D.1. Habitat Connectivity Models

Habitat connectivity models are available from the Washington Connected Landscapes Project.[vi] These models can be used to prioritize areas for maintaining and restoring habitat connectivity now and in the future as the climate changes. Available models include species corridor networks, landscape integrity corridor networks, and climate-gradient corridor networks. These models are available at two distinct scales (though for many species, only one scale is available or was selected for use by project participants): 1) **WHCWG Statewide** models span Washington State and surrounding areas of Oregon, Idaho, and British Columbia; 2) **WHCWG Columbia Plateau** models span the Columbia Plateau ecoregion within Washington State, and do not extend into British Columbia.

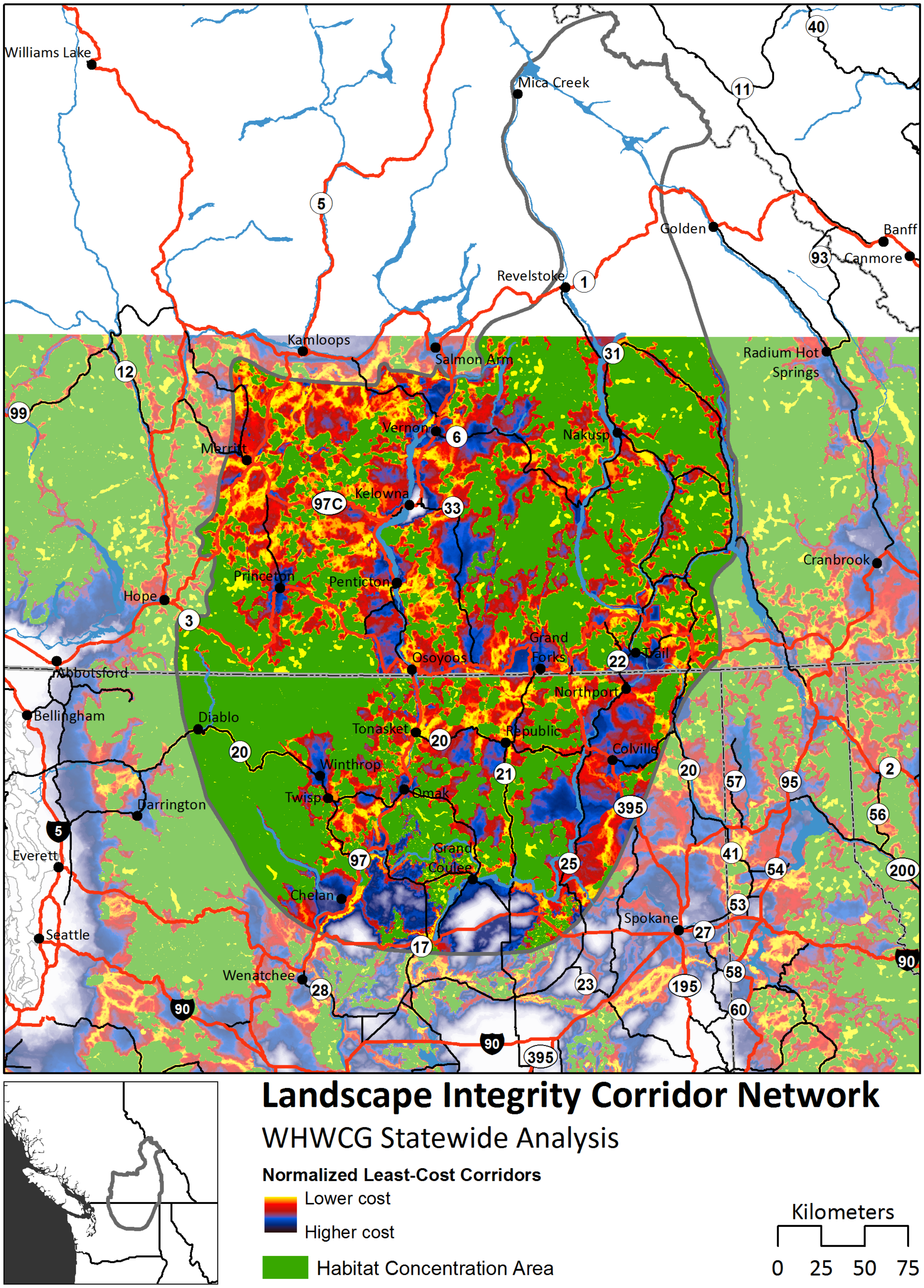
a) **WHCWG Statewide Analysis: Landscape Integrity Corridor Network.**[8] This map shows corridor networks connecting core habitat areas (green polygons) for areas of high landscape integrity (e.g., areas with few roads, agricultural areas, or urban areas). Corridors are represented as yellow areas, with resistance to movement increasing as yellow transitions to blue. Green areas represent large, contiguous core areas of high landscape integrity. The northern extent of this analysis falls just north of Kamloops, BC.

b) **WHCWG Statewide Analysis: Climate-Gradient Corridor Network (Temperature + Landscape Integrity).**[9] This map shows corridors (glowing white areas, with resistance to movement increasing as white fades to black) connecting core habitat areas (polygons, shaded to reflect mean annual temperatures) that are of high landscape integrity (i.e., have low levels of human modification) and differ in temperature by >1 ^{o}C. These corridors thus allow for movement between relatively warmer and cooler core habitat areas, while avoiding areas of low landscape integrity (e.g., roads, agricultural areas, urban areas), and minimizing major changes in temperature along the way (e.g., crossing over cold peaks or dipping into warm valleys). The northern extent of this analysis falls just north of Kamloops, BC.

[vi] For detailed methodology and data layers see http://www.waconnected.org.

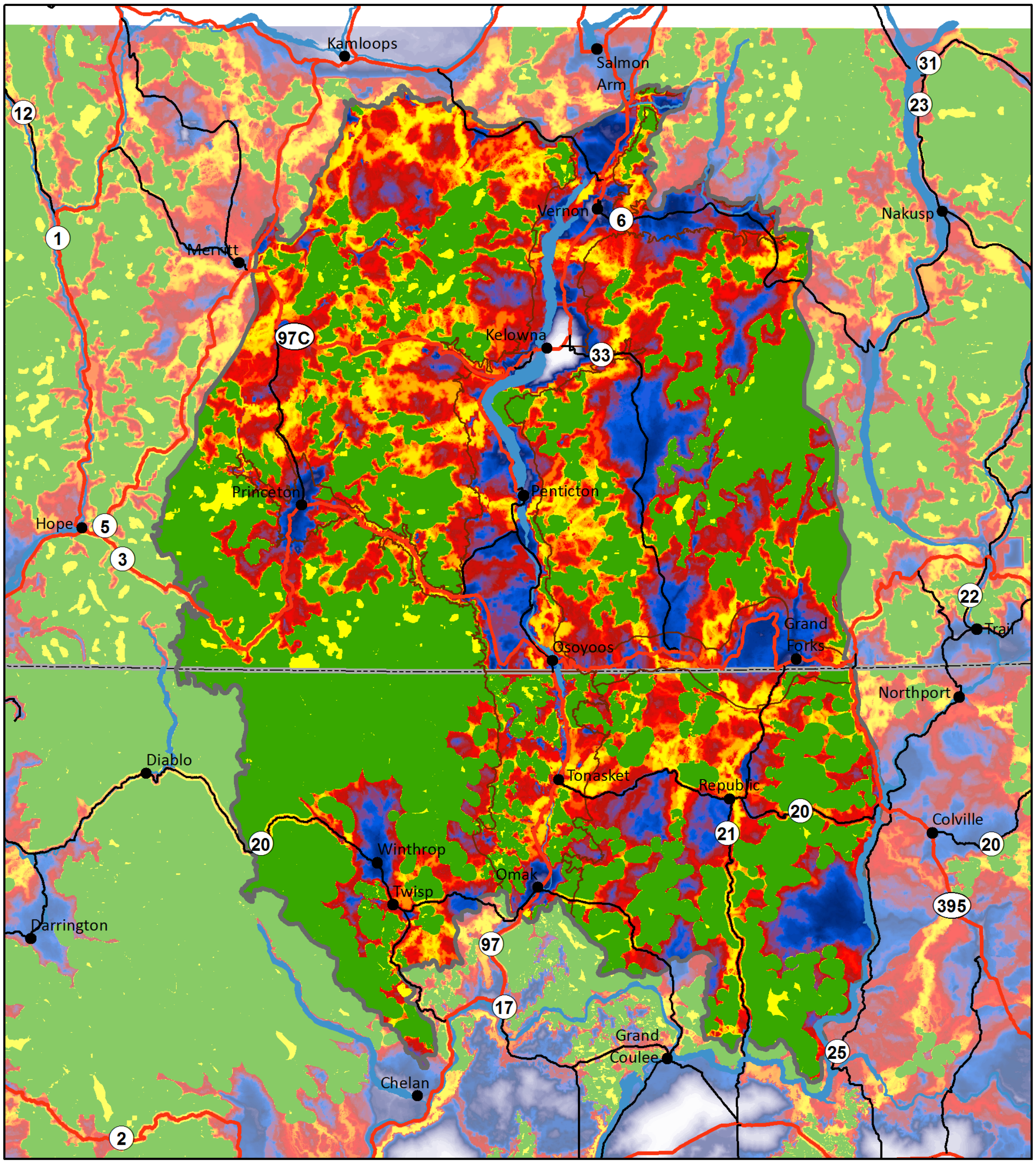
Appendix D.1a. WHCWG Statewide Analysis: Landscape Integrity Corridor Network

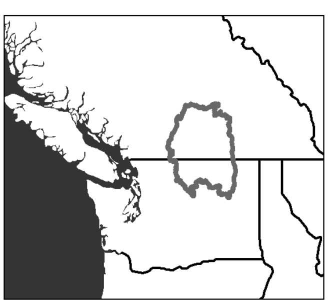
i) Extent: Okanagan Nation Territory



Appendix D.1a. WHCWG Statewide Analysis: Landscape Integrity Corridor Network

ii) Extent: Okanagan-Kettle Region





Landscape Integrity Corridor Network

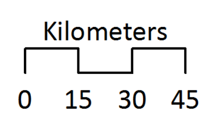
WHWCG Statewide Analysis

Normalized Least-Cost Corridors

Lower cost

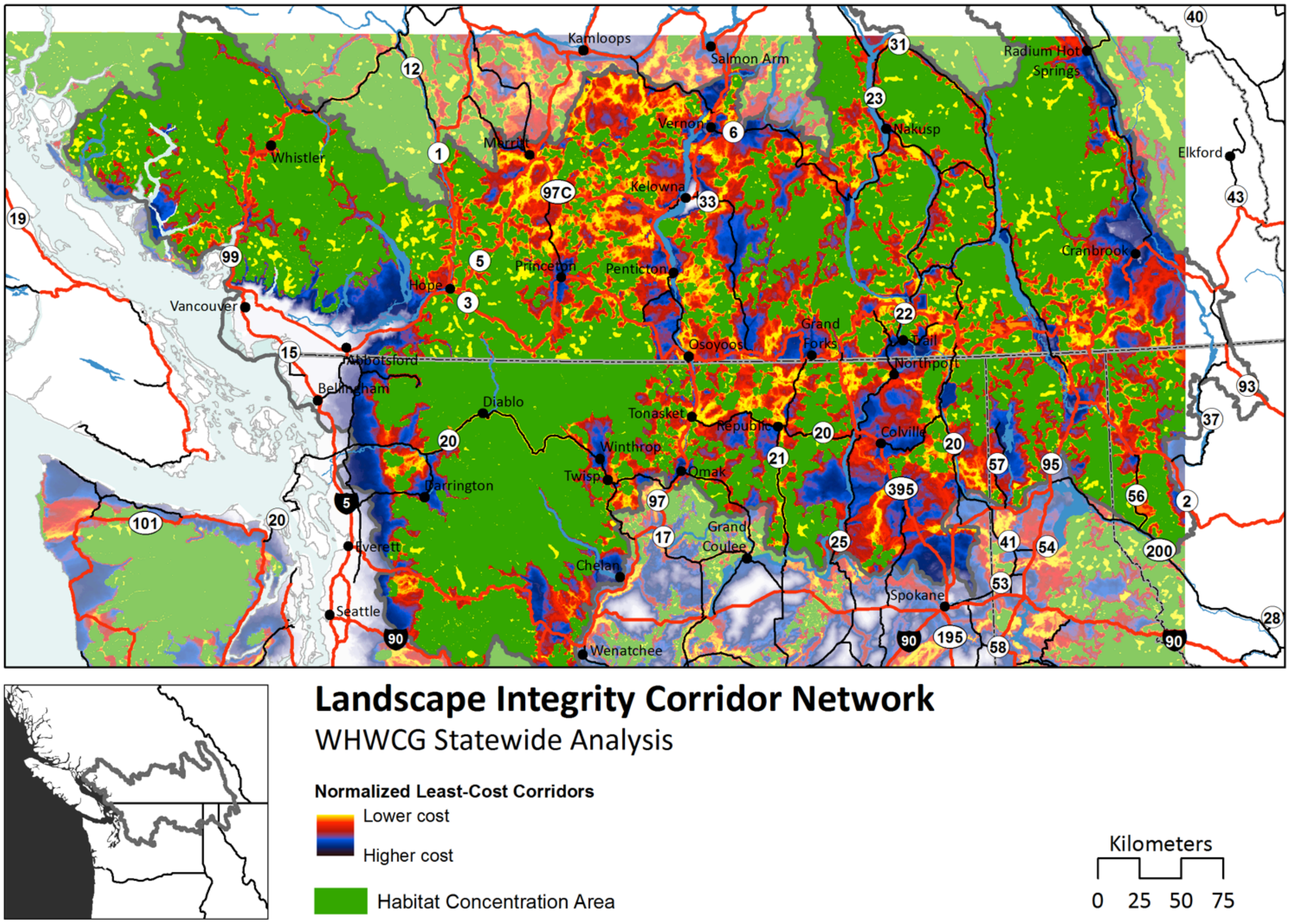
Higher cost

Habitat Concentration Area



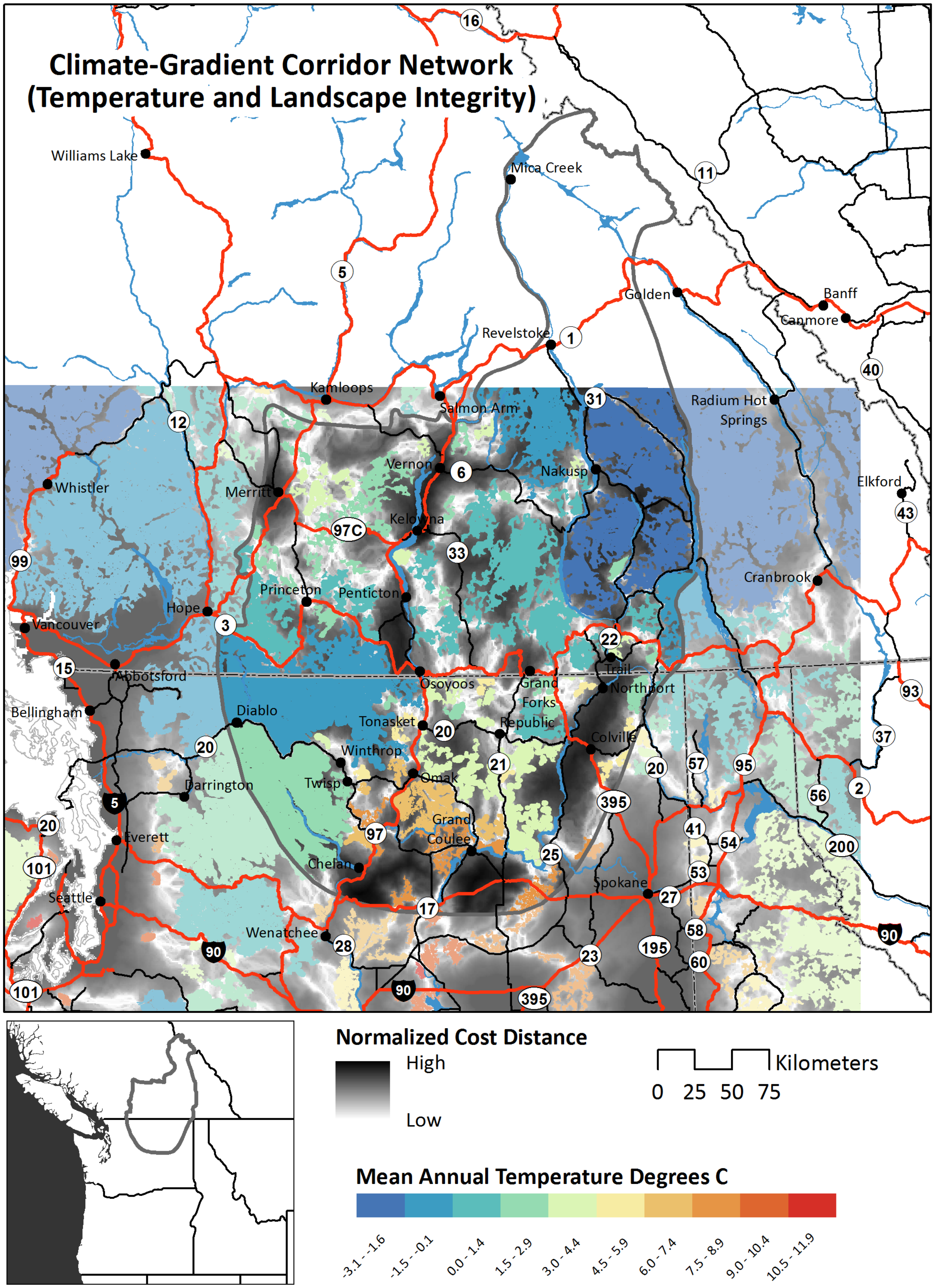
Appendix D.1a. WHCWG Statewide Analysis: Landscape Integrity Corridor Network

iii) Extent: Washington-British Columbia Transboundary Region



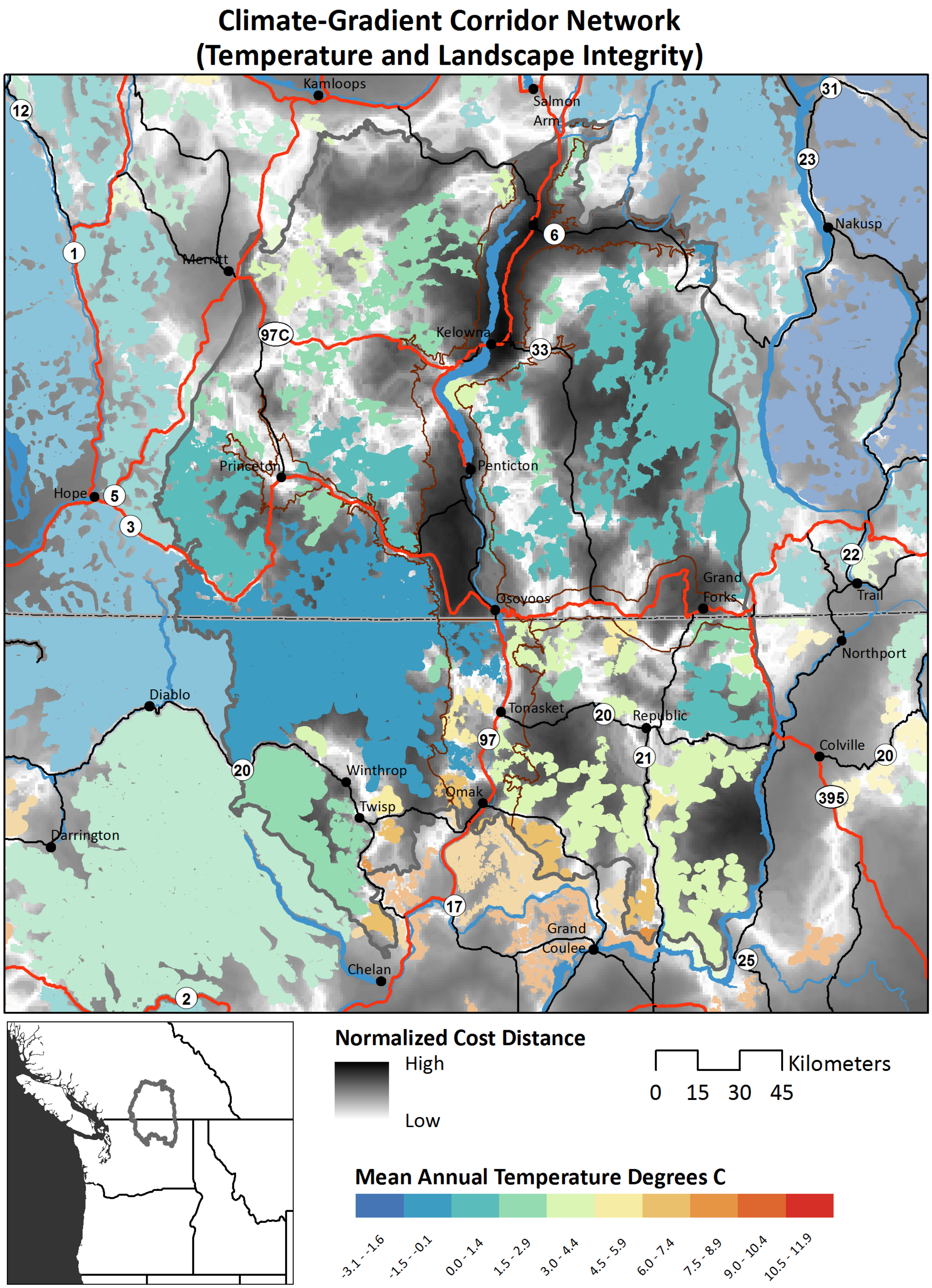
Appendix D.1b. WHCWG Statewide Analysis: Climate-Gradient Corridor Network (Temperature + Landscape Integrity)

i) Extent: Okanagan Nation Territory



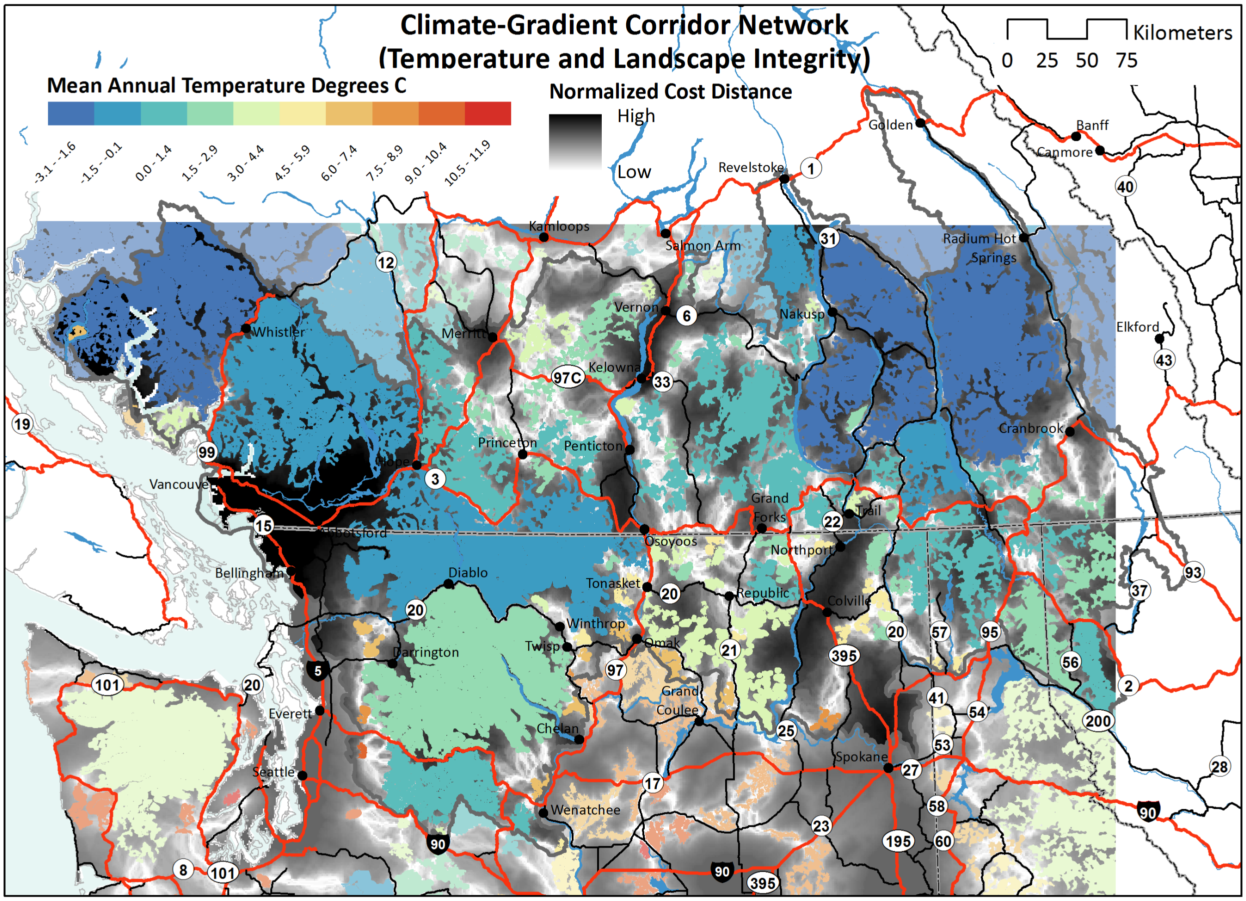
Appendix D.1b. WHCWG Statewide Analysis: Climate-Gradient Corridor Network (Temperature + Landscape Integrity)

ii) Extent: Okanagan-Kettle Region



Appendix D.1b. WHCWG Statewide Analysis: Climate-Gradient Corridor Network (Temperature + Landscape Integrity)

iii) Extent: Washington-British Columbia Transboundary Region



Appendix D.2. Conceptual Model of Habitat Connectivity

To identify potential climate impacts on transboundary whitebark pine habitat connectivity, project partners created a conceptual model that identifies the key landscape features and processes expected to influence whitebark pine habitat connectivity, which of those are expected to be influenced by climate, and how. Simplifying complex ecological systems in such a way can make it easier to identify specific climate impacts and adaptation actions. For this reason, conceptual models have been promoted as useful adaptation tools, and have been applied in a variety of other systems.[7] The whitebark pine conceptual model was developed using peer-reviewed articles and reports, project participant expertise, and review by species experts. That said, the resulting model is intentionally simplified, and should not be interpreted to represent a comprehensive assessment of the full suite of landscape features and processes contributing to whitebark pine habitat connectivity.

Conceptual models illustrate the relationships between the key landscape features (white boxes), ecological processes (rounded corner purple boxes), and human activities (rounded corner blue boxes) that influence the quality and permeability of core habitat and dispersal habitat for a given species. Climatic variables for which data on projected changes are available are highlighted with a yellow outline. Green arrows indicate a positive correlation between linked variables (i.e., as variable x increases variable y increases); note that a positive correlation is not necessarily beneficial to the species. Red arrows indicate a negative relationship between variables (i.e., as variable x increases, variable y decreases); again, negative correlations are not necessarily harmful to the species.

Expert reviewers for the whitebark pine conceptual model included:

- Alison Peatt, RPBio, Environmental planner for South Okanagan-Similkameen communities
- Bob Keane, USFS Rocky Mountain Research Station
- Michael Murray, BC FLNRO
- Greg Ettl, University of Washington

Key references used to create the whitebark pine conceptual model included:

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Burns, R. M. and B. H. Honkala. 1990. Silvics of North America: 1. conifers: 2. hardwoods. vol. 2. Agriculture Handbook 654. U.S. Department of Agriculture, Forest Service, Washington, DC.

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Franklin, J. F., W. H. Moir, G. W. Douglas, and C. Wiberg. 1971. Invasion of subalpine meadows by trees in the Cascade range, Washington and Oregon. Arctic and Alpine Research 3:215–224.

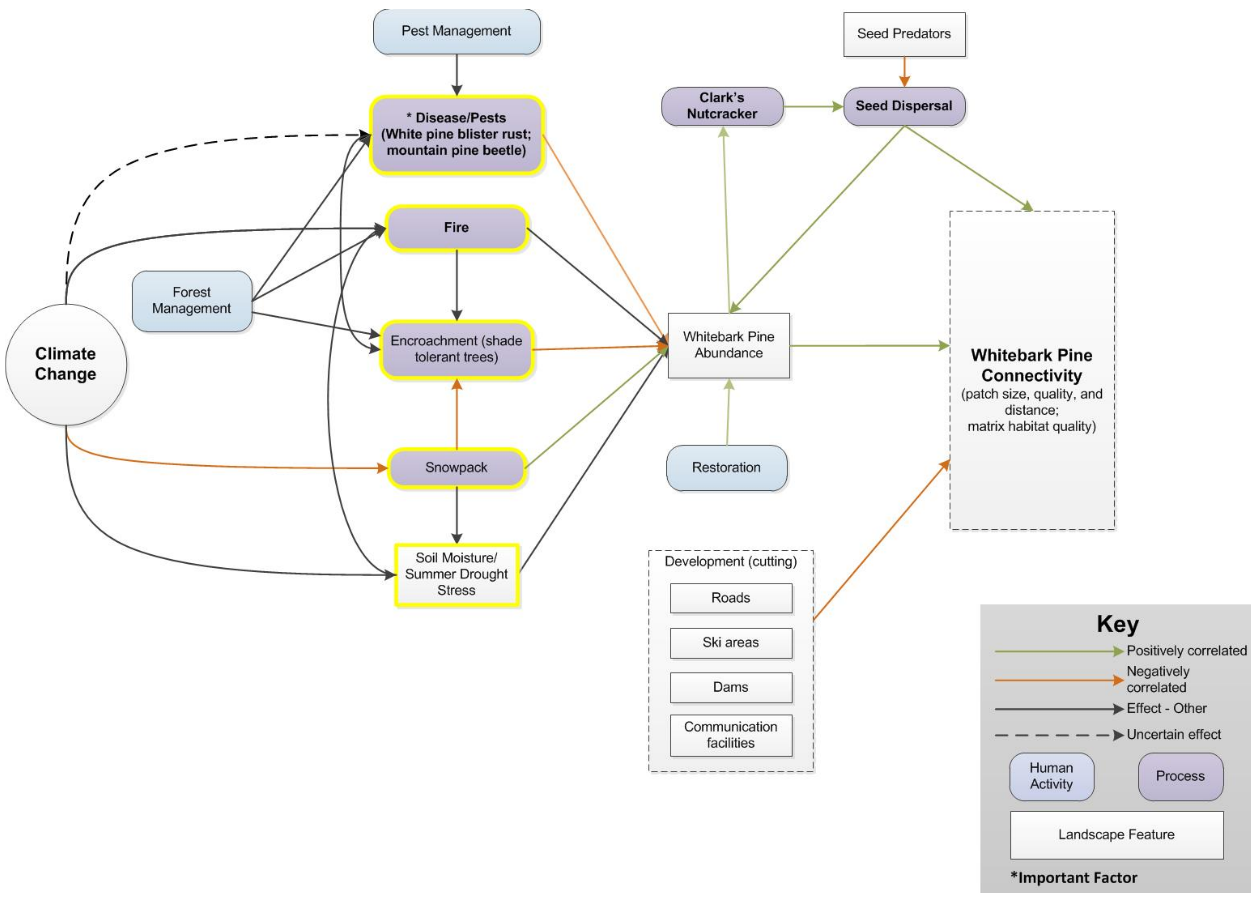
Harsch, M. A., P. E. Hulme, M. S. McGlone, and R. P. Duncan. 2009. Are treelines advancing? A global meta–analysis of treeline response to climate warming. Ecology Letters 12:1040–1049.

Littell, J., E. Oneil, D. McKenzie, J. Hicke, J. Lutz, R. Norheim, and M. Elsner. 2010. Forest ecosystems, disturbance, and climatic change in Washington State, USA. Climatic Change 102:129-158.

Tomback, D. F., S. F. Arno, and R. E. Keane, eds. 2001. Whitebark pine communities: ecology and restoration. Island Press, Washington, D.C.

Tranquillini, W. 1979. Physiological ecology of the alpine timberline. Springer–Verlag, New York, NY.

Appendix D.2. Conceptual Model of Whitebark Pine Habitat Connectivity



Appendix D.3. Climatic Niche Models

Climatic niche models (CNM) mathematically define the climatic conditions within each species' current geographic distribution, and then apply projected climate changes to identify where on the landscape those climate conditions are projected to be located in the future. These maps show CNM results based on results from two CMIP3 Global Circulation Models (GCMs): CGCM3.1(T47) and UKMO-HadCM3.[vii] Both models use the A2 (high) emissions scenario.[viii] CNMs are based on climate conditions alone and do not account for dispersal ability, genetic adaptation, interspecies interactions, or other aspects of habitat suitability. Once projected range shifts were modeled, current land uses and projected vegetation types (identified using Shafer et al. 2015[ix]) that are unlikely to support species occurrence were removed. For example, areas currently defined as urban were removed for species unable to live in urban landscapes, and grassland habitats were removed for forest-dependent species. Both would be shown as unsuitable.

Dark gray areas indicate areas of the species' current range that are projected to remain climatically suitable by both GCMs (i.e., range is expected to remain "stable"). Dark pink areas are projected to become less climatically suitable by both GCMs (i.e., range is expected to "contract"). Light pink areas are projected to become less suitable under one model but remain stable under the other. Dark green areas are areas that are not within the species' current range but are projected to become climatically suitable by both GCMs (i.e., the range is expected to "expand"). Light green areas are projected to become climatically suitable by one GCM, but not the other. Hashed areas indicate the current estimated distribution of whitebark pine.[x]

[vii] CGCM3.1(T47) and UKMO-HadCM3 are two Global Circulation Models (GCMs) which each project different potential future climate scenarios. The UKMO-HadCM3 model projects a much hotter and drier summer, while the CGCM3.1(T47) projects greater precipitation increases in spring, summer and fall. For these reasons, the UKMO-HadCM3 could be considered a "hot-dry" future, while the CGCM3.1(T47) could be considered a "warm-wet" future within the Pacific Northwest.

[viii] Emissions scenarios were developed by climate modeling centers for use in modeling global and regional climate-related effects. A2 is a high, "business as usual" scenario in which emissions of greenhouse gases continue to rise until the end of the 21st century, and atmospheric CO_2 concentrations more than triple by 2100 relative to pre-industrial levels.

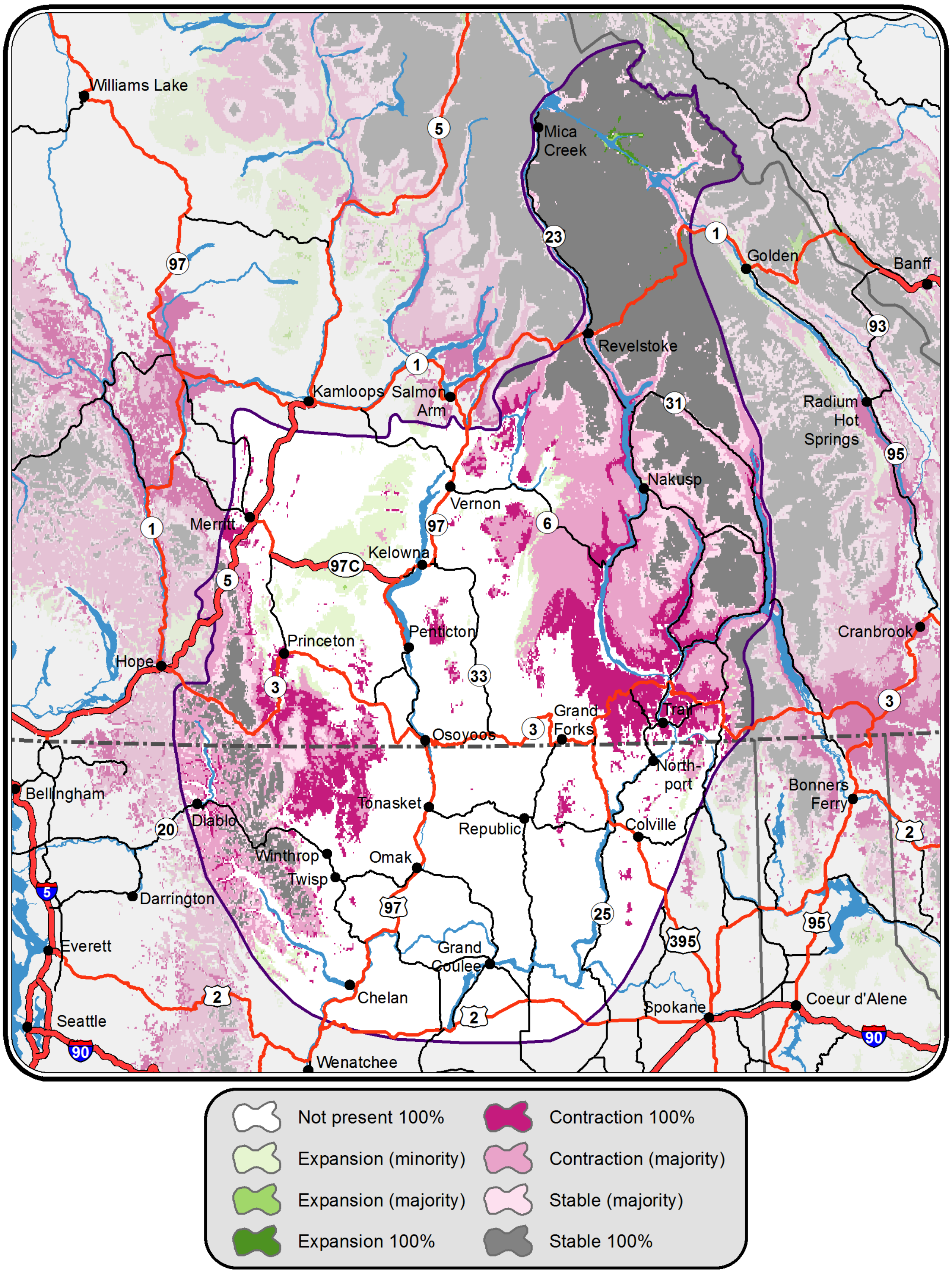
[ix] Shafer, S.L., Bartlein, P.J , Gray, E.M., and R.T. Pelltier. 2015. Projected future vegetation changes for the northwest United States and southwest Canada at a fine spatial resolution using a dynamic global vegetation model. *PLoS ONE* 10: e0138759. doi:10.1371/journal.pone.0138759

[x] Whitebark Pine Ecosystem Foundation. 2014. Whitebark pine and limber pine range maps. Available at: http://whitebarkfound.org/?page_id=823 (Accessed October 2015).

Appendix D.3. Whitebark Pine Climatic Niche Model

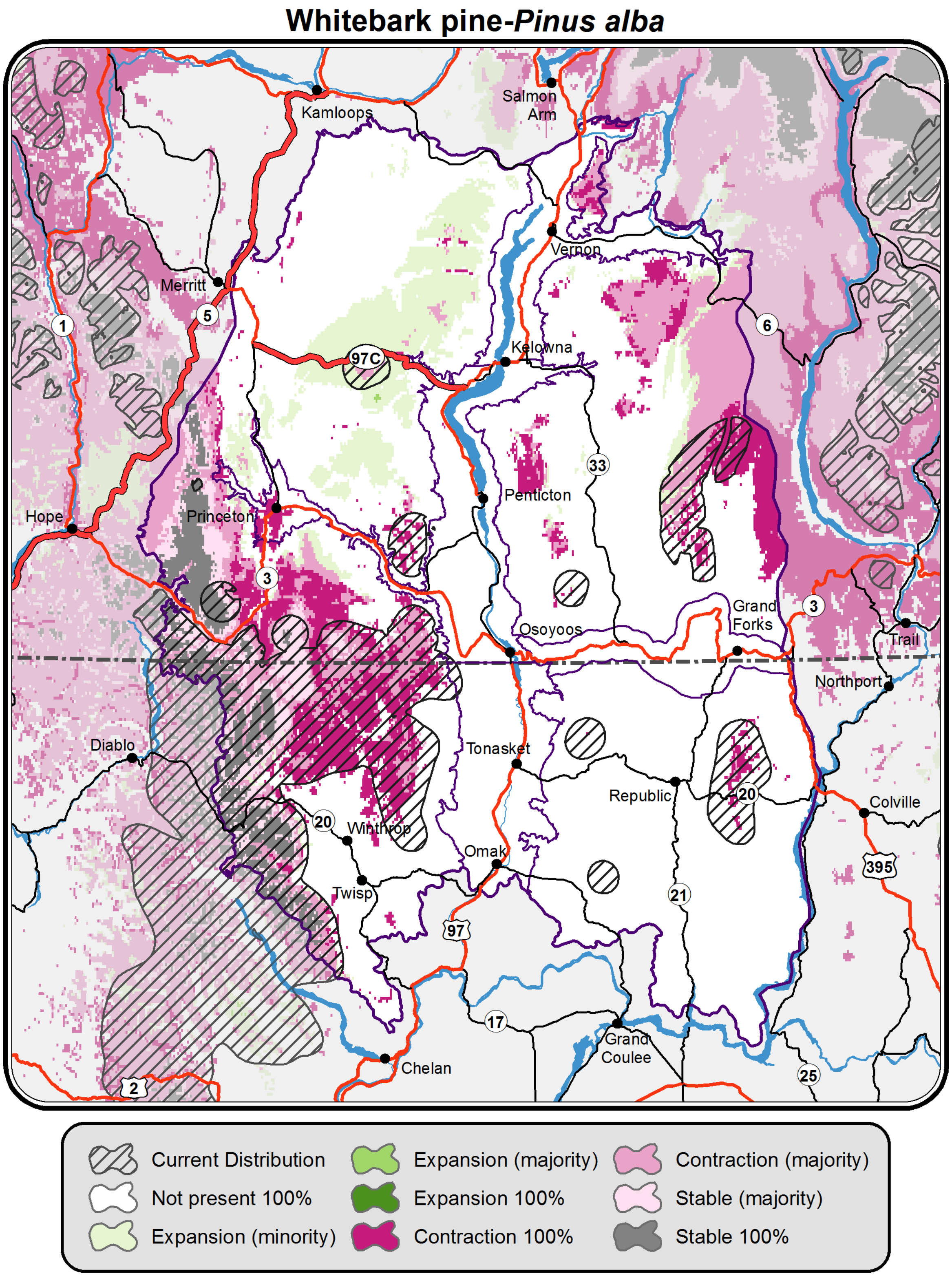
i) Extent: Okanagan Nation Territory

Whitebark pine-*Pinus alba*



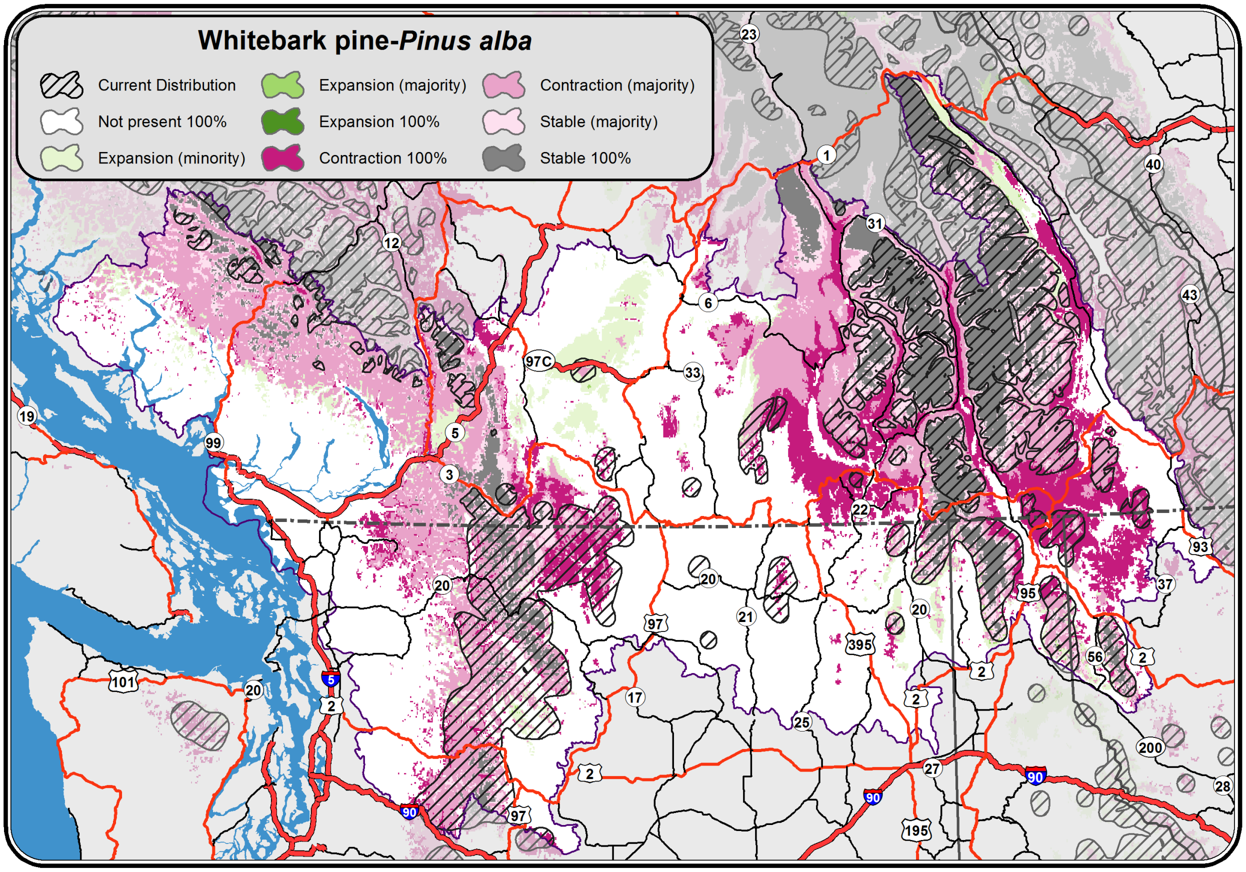
Appendix D.3. Whitebark Pine Climatic Niche Model

ii) Extent: Okanagan-Kettle Region



Appendix D.3. Whitebark Pine Climatic Niche Model

iii) Extent: Washington-British Columbia Transboundary Region



Appendix D.4. Projected Changes in Vegetation

Two types of models are available that project future changes in vegetation that could affect a species' habitat connectivity: climatic niche models and mechanistic models. Climatic niche vegetation models mathematically define the climatic conditions within a given vegetation type's current distribution and then project where on the landscape those conditions are expected to occur in the future. These models do not incorporate other important factors that determine vegetation such as soil suitability, dispersal, competition, and fire. In contrast, mechanistic vegetation models do incorporate these ecological processes, as well as projected climate changes and the potential effects of carbon dioxide fertilization. However, mechanistic models only project changes to very general vegetation types (e.g., cold forest, shrub steppe, or grassland). Both types of models included below show vegetation model results based on results from two CMIP3 Global Circulation Models (GCMs): CGCM3.1(T47) and UKMO-HadCM3.[xi] Both models also use the A2 (high) emissions scenario.[xii]

a) **Biome Climatic Niche Vegetation Model.**[xiii] This climatic niche vegetation model shows the projected response of biomes or forest types to projected climate change.

b) **Mechanistic Vegetation Model.**[xiv] This mechanistic vegetation model shows simulated vegetation composition and distribution patterns under climate change.

[xi] CGCM3.1(T47) and UKMO-HadCM3 are two Global Circulation Models (GCMs) which each project different potential future climate scenarios. The UKMO-HadCM3 model projects a much hotter and drier summer, while the CGCM3.1(T47) projects greater precipitation increases in spring, summer and fall. For these reasons, the UKMO-HadCM3 could be considered a "hot-dry" future, while the CGCM3.1(T47) could be considered a "warm-wet" future within the Pacific Northwest.

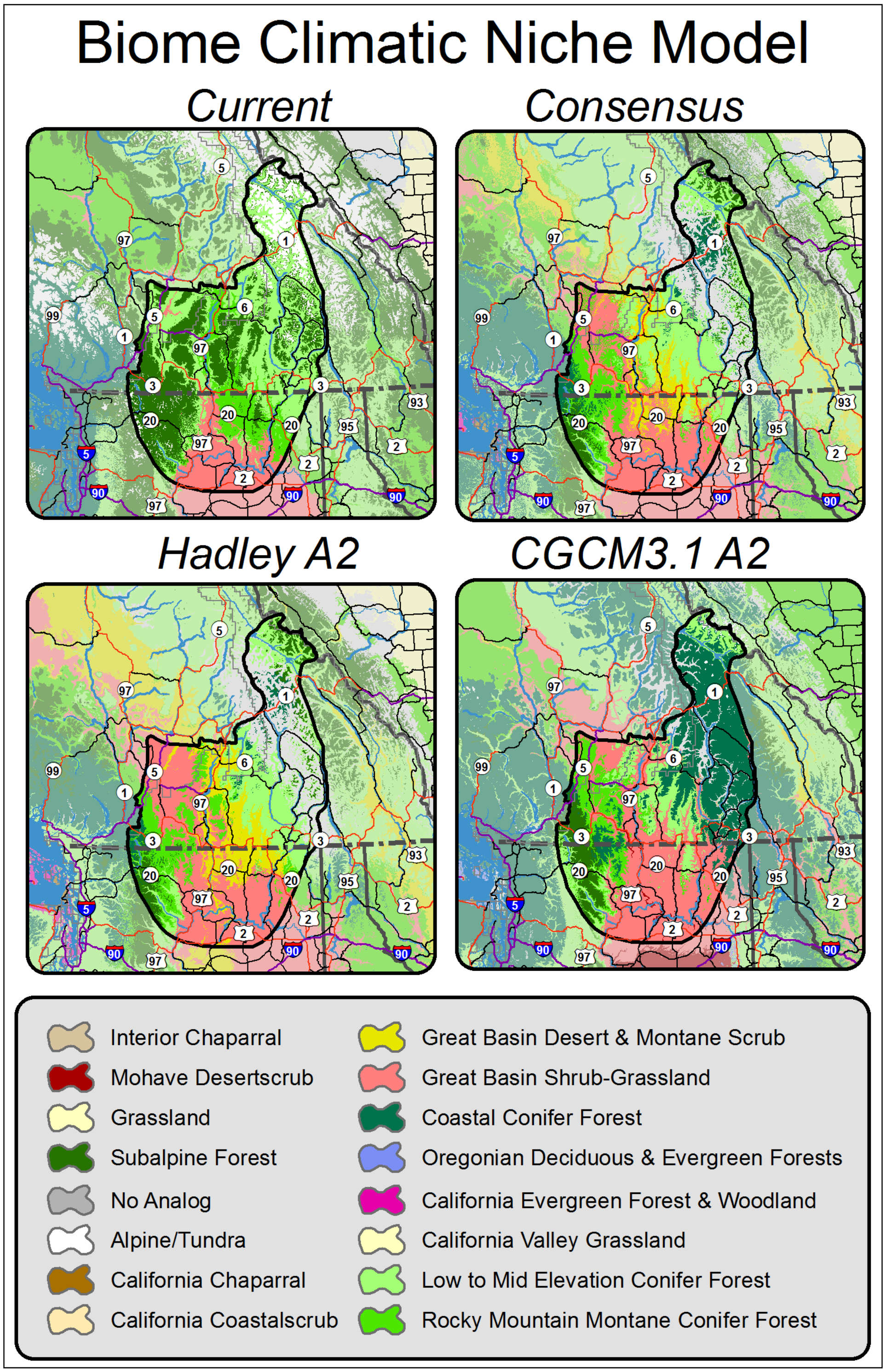
[xii] Emissions scenarios were developed by climate modeling centers for use in modeling global and regional climate-related effects. A2 is a high, "business as usual" scenario in which emissions of greenhouse gases continue to rise until the end of the 21st century, and atmospheric CO_2 concentrations more than triple by 2100 relative to pre-industrial levels.

[xiii] Rehfeldt, G.E., Crookston, N.L., Sánez-Romero, C., Campbell, E.M. 2012. North American vegetation model for land-use planning in a changing climate: a solution to large classification problems. *Ecological Applications* 22: 119-141.

[xiv] Shafer, S.L., Bartlein, P.J , Gray, E.M., and R.T. Pelltier. 2015. Projected future vegetation changes for the Northwest United States and Southwest Canada at a fine spatial resolution using a dynamic global vegetation model. *PLoS ONE* 10: e0138759. doi:10.1371/journal.pone.0138759.

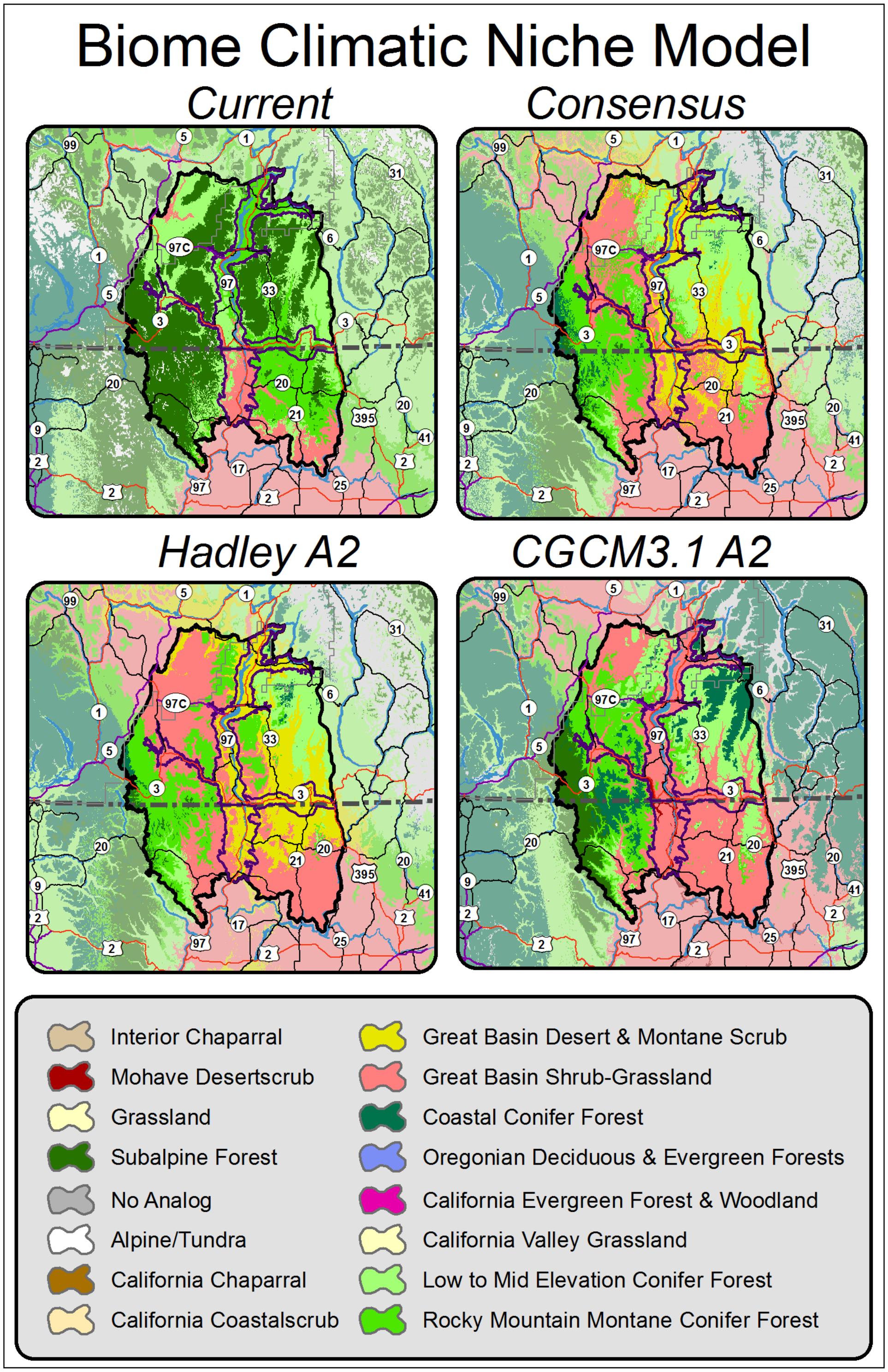
Appendix D.4a. Biome Climatic Niche Model

i) Extent: Okanagan Nation Territory



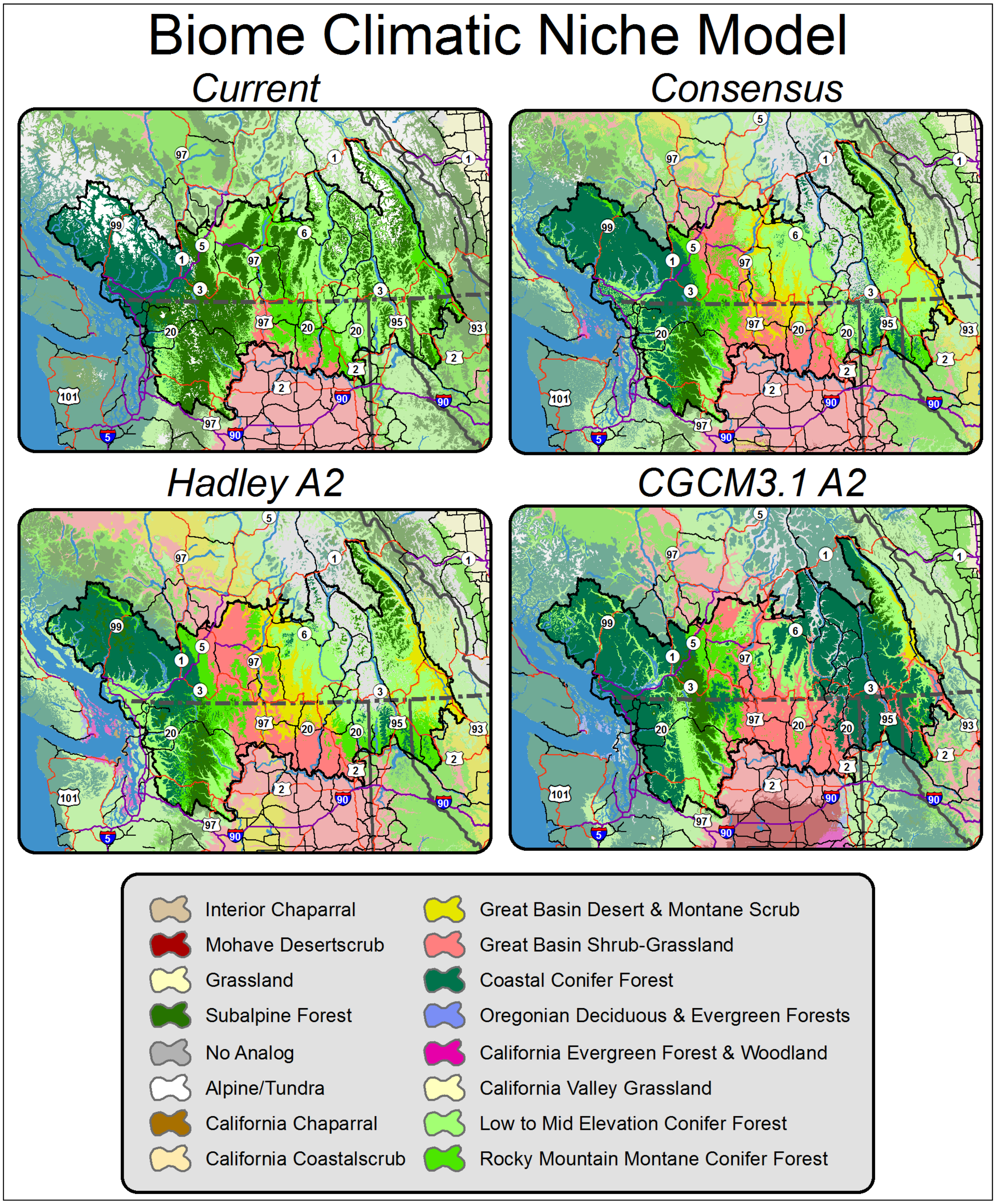
Appendix D.4a. Biome Climatic Niche Model

ii) Extent: Okanagan-Kettle Region



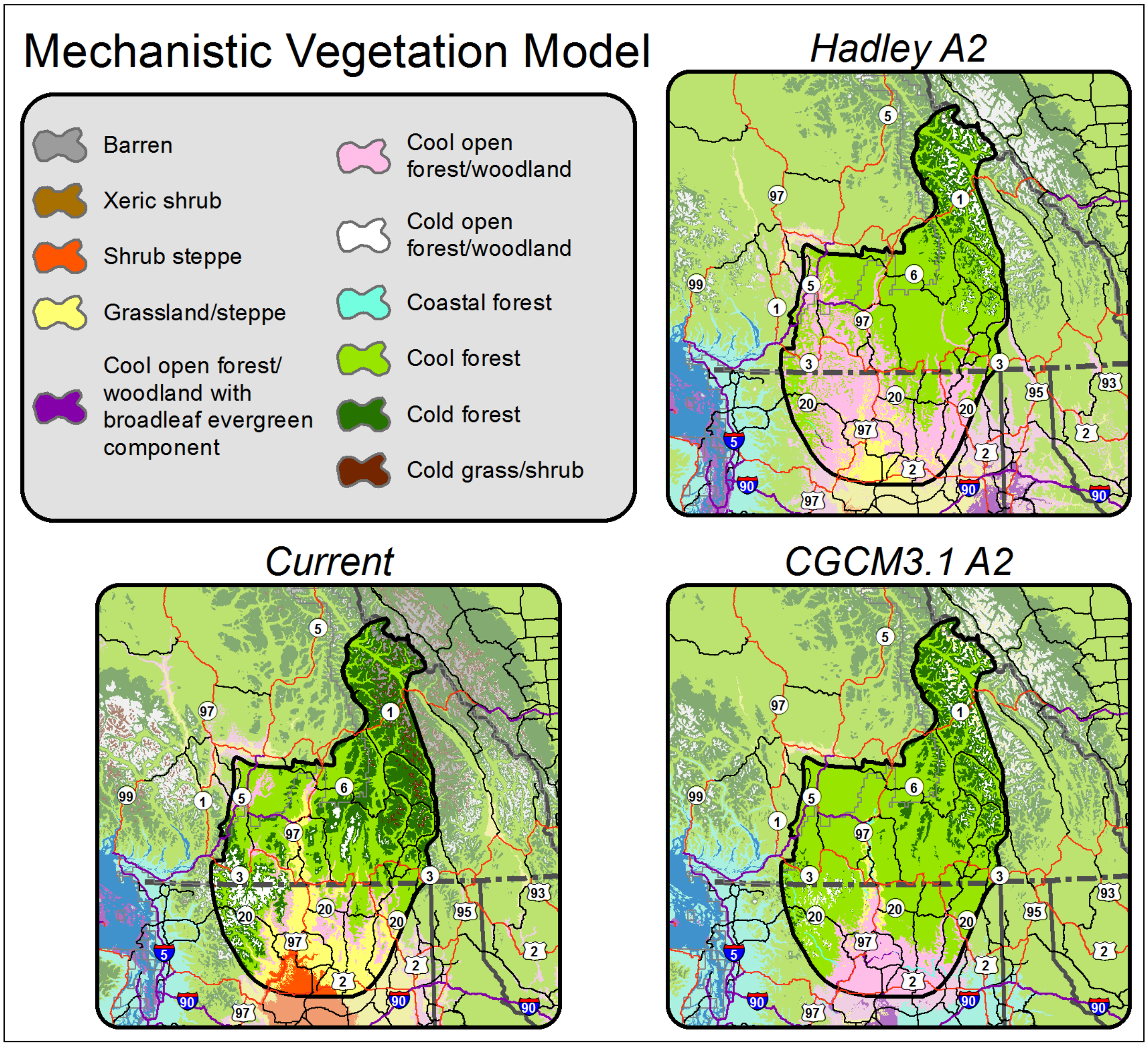
Appendix D.4a. Biome Climatic Niche Model

iii) Extent: Washington-British Columbia Transboundary Region



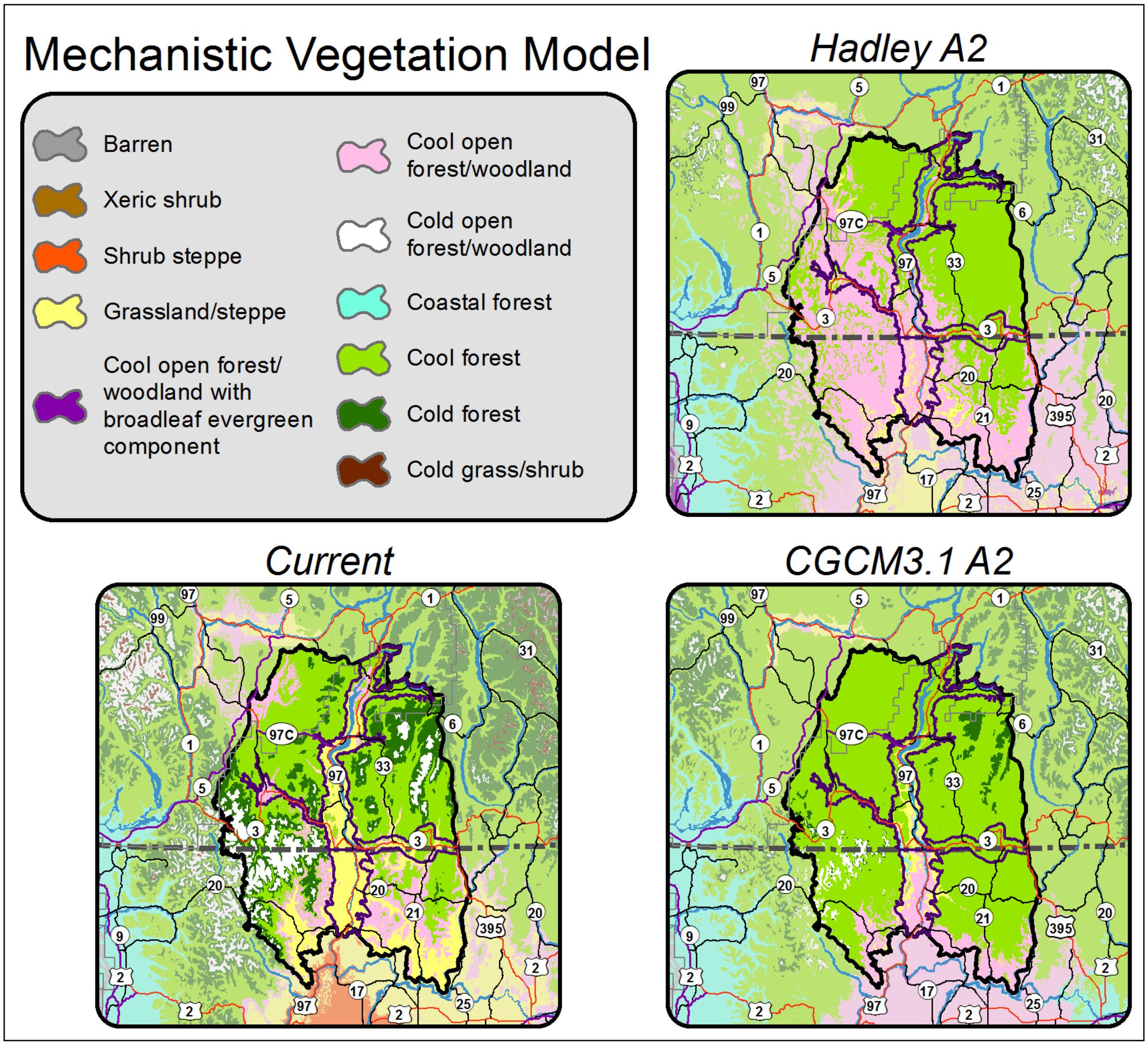
Appendix D.4b. Mechanistic Vegetation Model

i) Extent: Okanagan Nation Territory



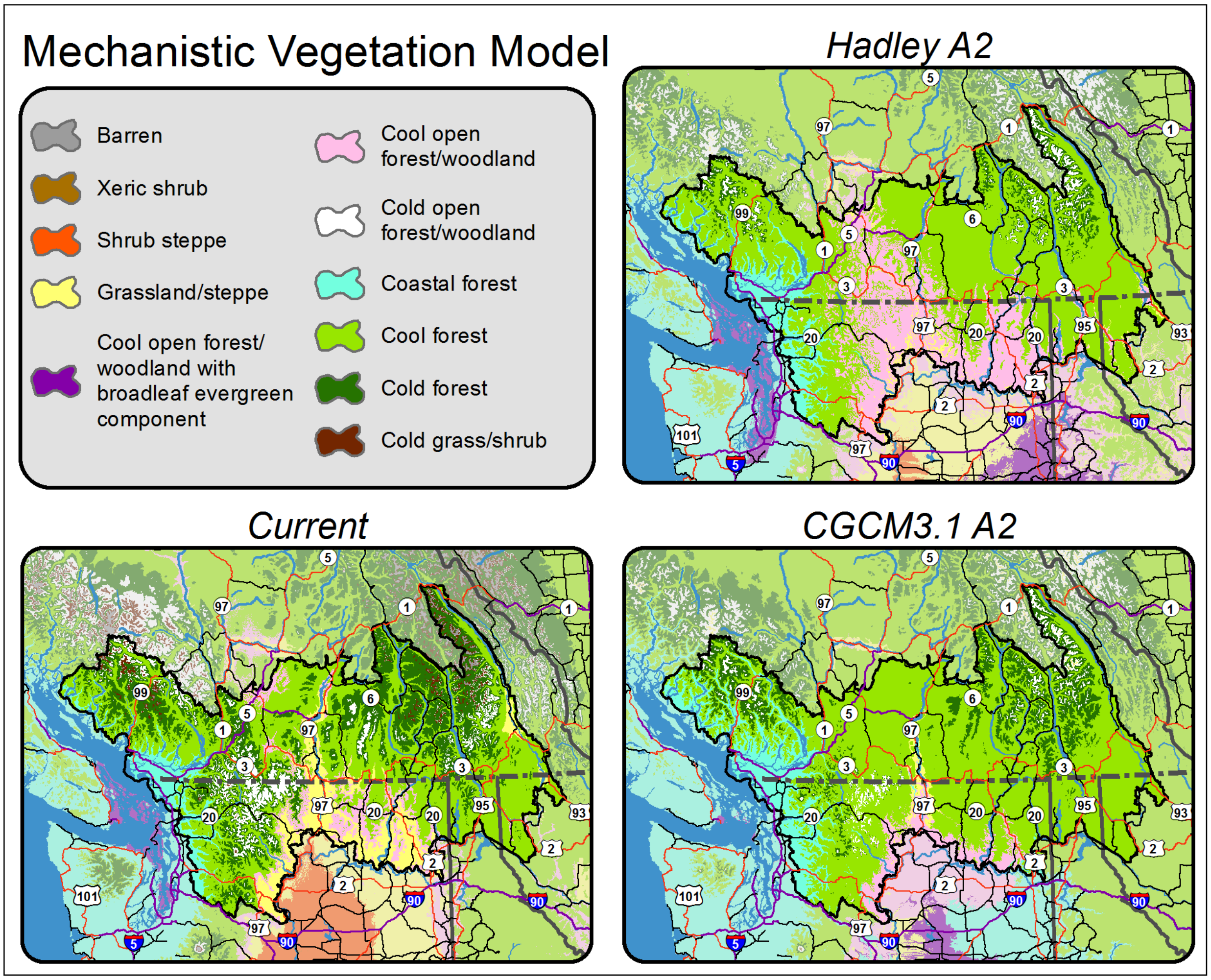
Appendix D.4b. Mechanistic Vegetation Model

ii) Extent: Okanagan-Kettle Region



Appendix D.4b. Mechanistic Vegetation Model

iii) Extent: Washington-British Columbia Transboundary Region



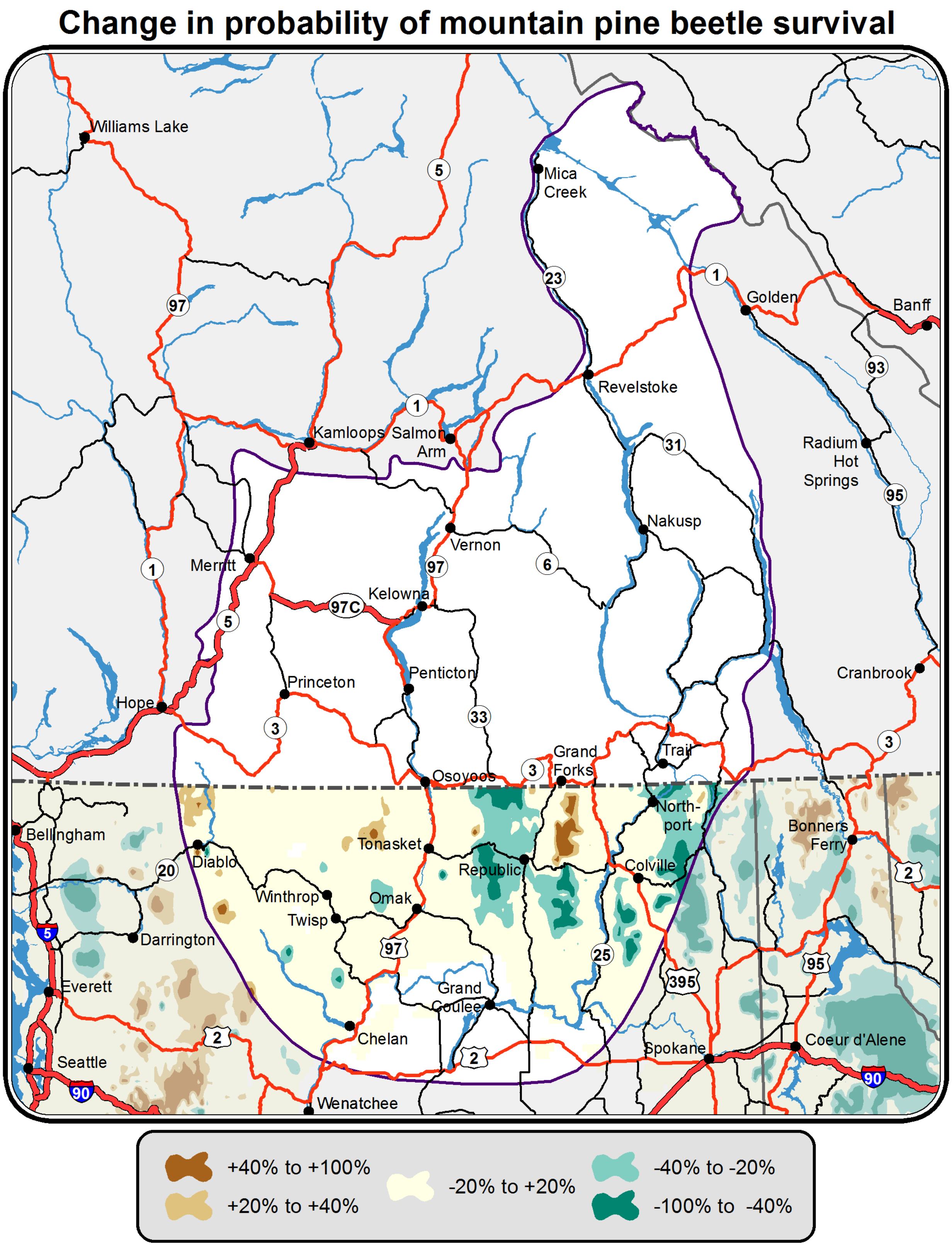
Appendix D.5. Projected Changes in Probability of Mountain Pine Beetle Survival

Projected changes in the probability of climatic suitability for mountain pine beetles for the period 2001 to 2030 (relative to 1961 to 1990), where brown indicates areas where pine beetles are projected to increase in the future and green indicates areas where pine beetles are projected to decrease in the future.[xv,xvi]

[xv] Mote, P.W., Snover, A.K., Capalbo, S.M., Eigenbrode, S., Glick, P., Littell, J.S., Raymondi, R., Reeder, S. 2014. Chapter 21 in *Climate Change Impacts in the United States: The Third U.S. National Climate Assessment*, J. Melillo, Terese (T.C.) Richmond, and G.W. Yohe, Eds., U.S. Global Change Research Program, 16-1-nn.
[xvi] Changes in probability of survival are based on climate-dependent factors important in beetle population success, including cold tolerance, spring precipitation, and seasonal heat accumulation.[xv] Projections are only available for the United States.

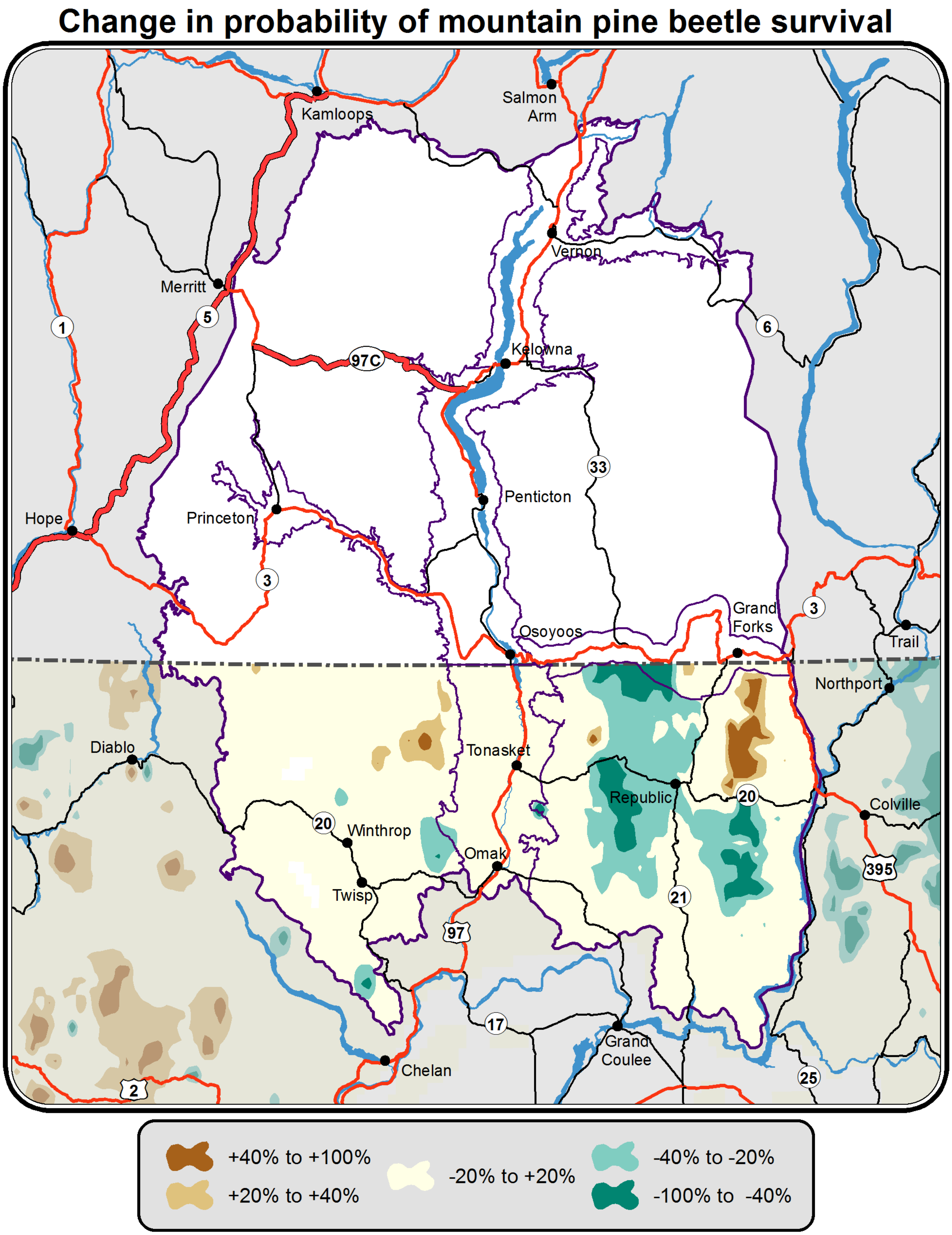
Appendix D.5. Probability of Mountain Pine Beetle Survival

i) Extent: Okanagan Nation Territory



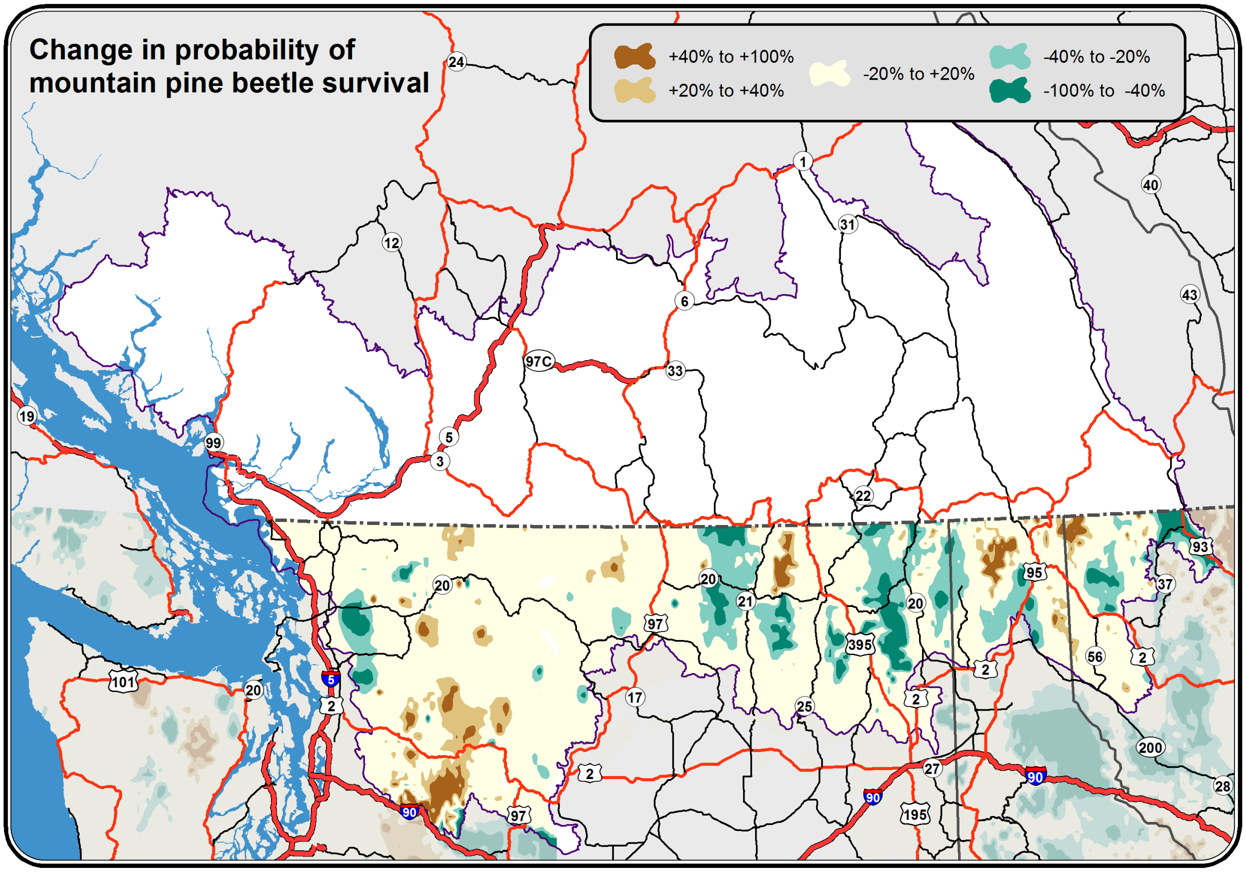
Appendix D.5. Probability of Mountain Pine Beetle Survival

ii) Extent: Okanagan-Kettle Region



Appendix D.5. Probability of Mountain Pine Beetle Survival

iii) Extent: Washington-British Columbia Transboundary Region



Appendix D.6. Projected Changes in Relevant Climate Variables

The following projections of future climate were identified by project partners as being most relevant to understanding and addressing climate impacts on whitebark pine connectivity.[xvii] Future climate projections were gathered from two sources, except where otherwise noted: 1) the Integrated Scenarios of the Pacific Northwest Environment,[10] which is limited to the extent of the Columbia Basin; and the Pacific Climate Impacts Consortium's Regional Analysis Tool,[11] which spans the full transboundary region. For many climatic variables, noticeable differences in the magnitude of future changes can be seen at the US-Canada border; this artifact results from differences on either side of the border in the number of weather stations, the way temperature and precipitation were measured, and differences in the approach used to process these data to produce gridded estimates of daily weather variations.

a) **Spring (April 1st) Snowpack.** This map snows the percent change in snow water equivalent (SWE) on April 1st. April 1st is the approximate current timing of peak annual snowpack in Northwest mountains. SWE is a measure of the total amount of water contained in the snowpack. Projected decreases in SWE are depicted by the yellow to red shading.

b) **Length of Snow Season.** This map shows the projected change in the length of the snow season, defined as the number of days between the first and last days of the season with at least 10% of annual maximum snow water equivalent. Projected changes in snow season length are depicted by the yellow to red shading.

c) **Soil Moisture, July-September.** This map shows the projected change, in percent, in summer soil moisture. Projected changes in soil moisture are depicted by the brown to green shading.

d) **Days with High Fire Risk** (Energy Release Component, ERC > 95th percentile). This map shows the projected change in the number of days when the ERC – a commonly used metric to project the potential and risk of wildfire – is greater than the historical 95th percentile among all daily values.[xviii]

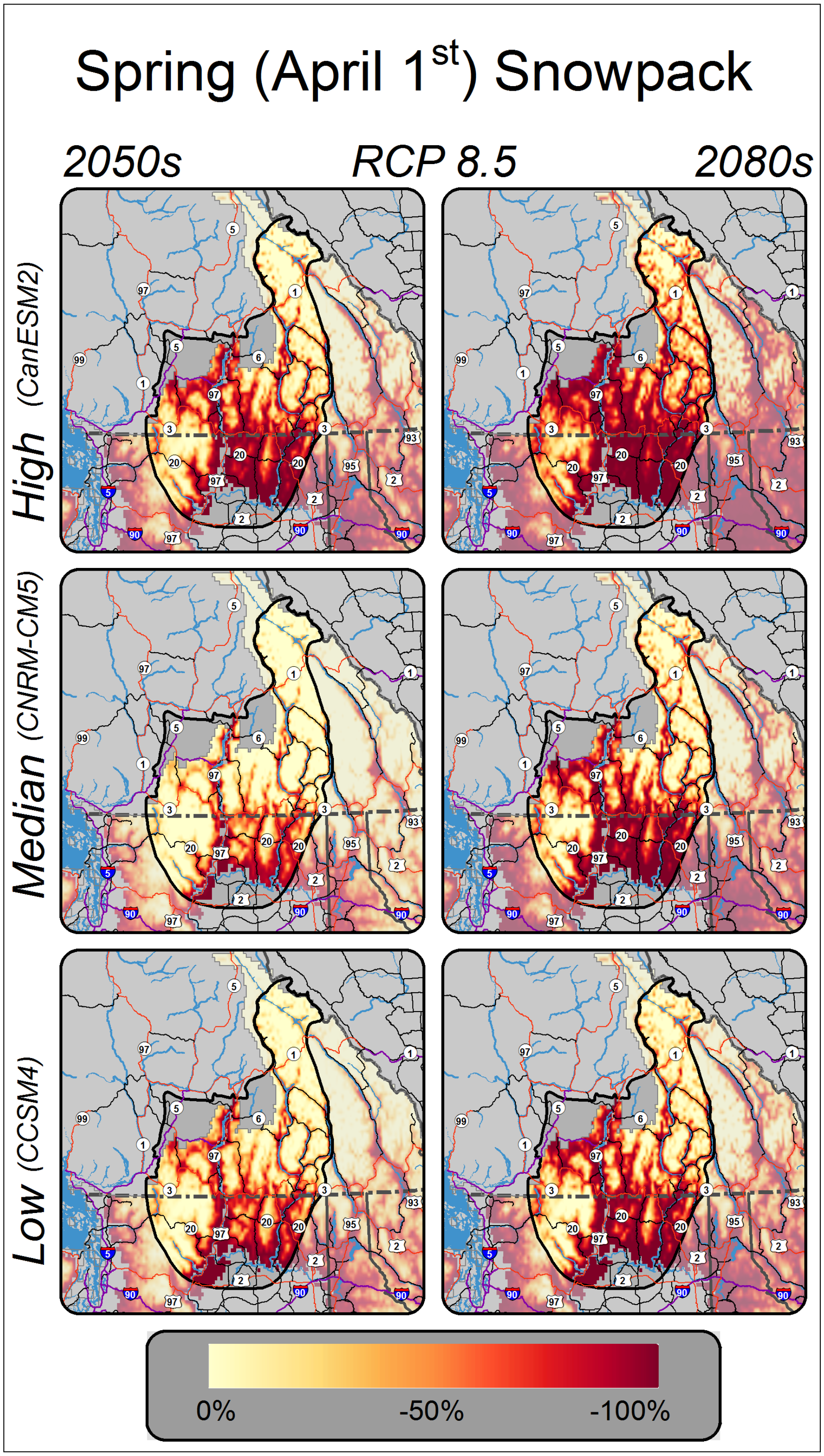
e) **Water Deficit, July-September.** This map shows the projected change, in percent, in water deficit. Water deficit is defined as the difference between potential evapotranspiration (PET) and actual evapotranspiration (AET), PET - AET. A positive value for PET – AET means that atmospheric demand for water is greater than the actual supply available.

[xvii] All projections but "Days with High Fire Risk" are evaluated for the 2050s (2040-2069) and the 2080s (2070-2099), based on 3 global climate models (a high (CanESM2), median (CNRM-CM5), and low (CCSM4)), under a high greenhouse gas scenario (RCP 8.5). "Days with High Fire Risk" is evaluated for the 2050s, based on 3 global climate models (a high (CanESM2), median (CNRM-CM5), and low (MIROC5)) using the RCP 8.5 (high) emissions scenario.

[xviii] Abatzoglou, J.T. 2013. Development of gridded surface meteorological data for ecological applications and modeling. *International Journal of Climatology*, 33(1): 121-131.

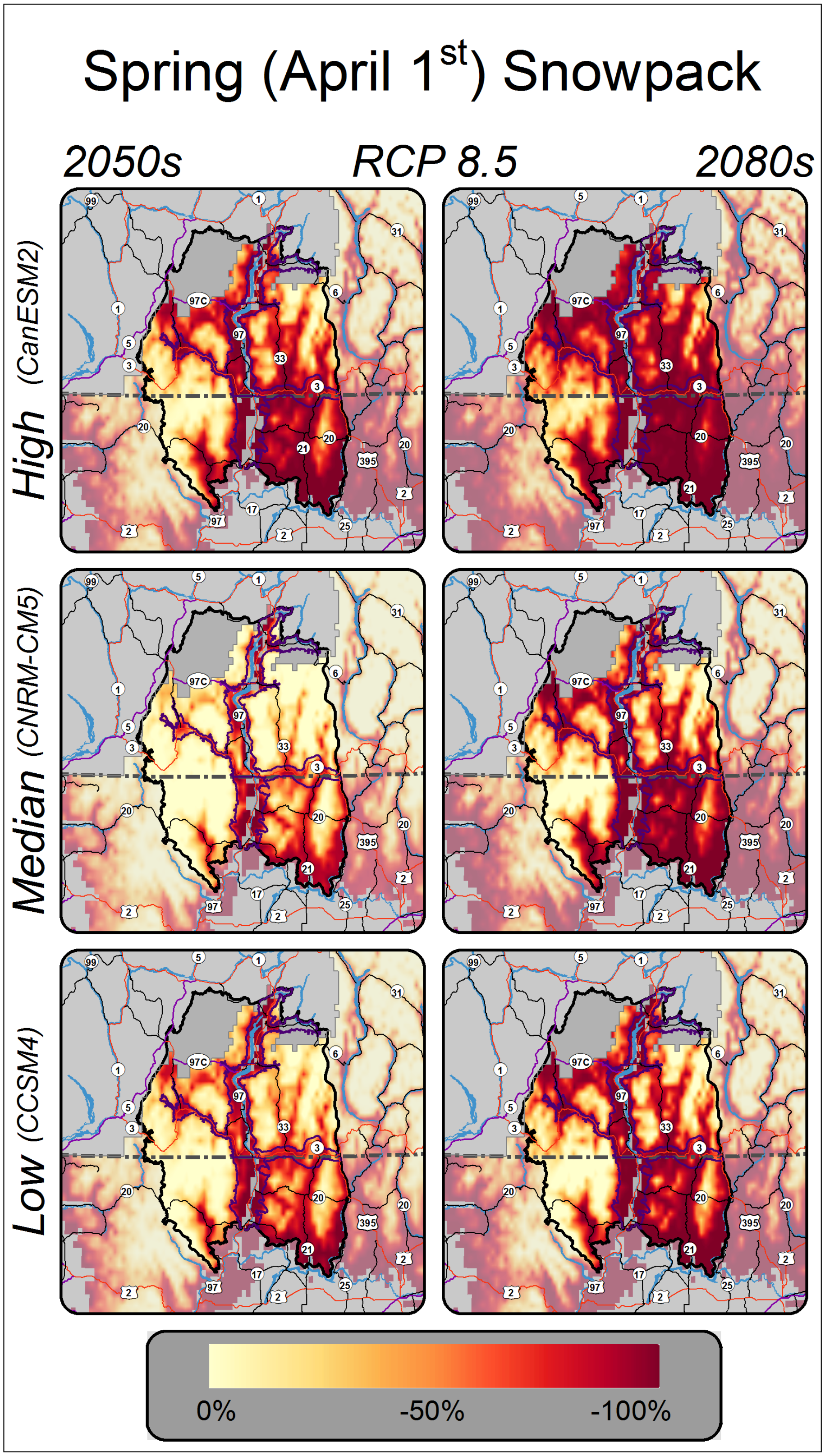
Appendix D.6a. Spring (April 1st) Snowpack

i) Extent: Okanagan Nation Territory



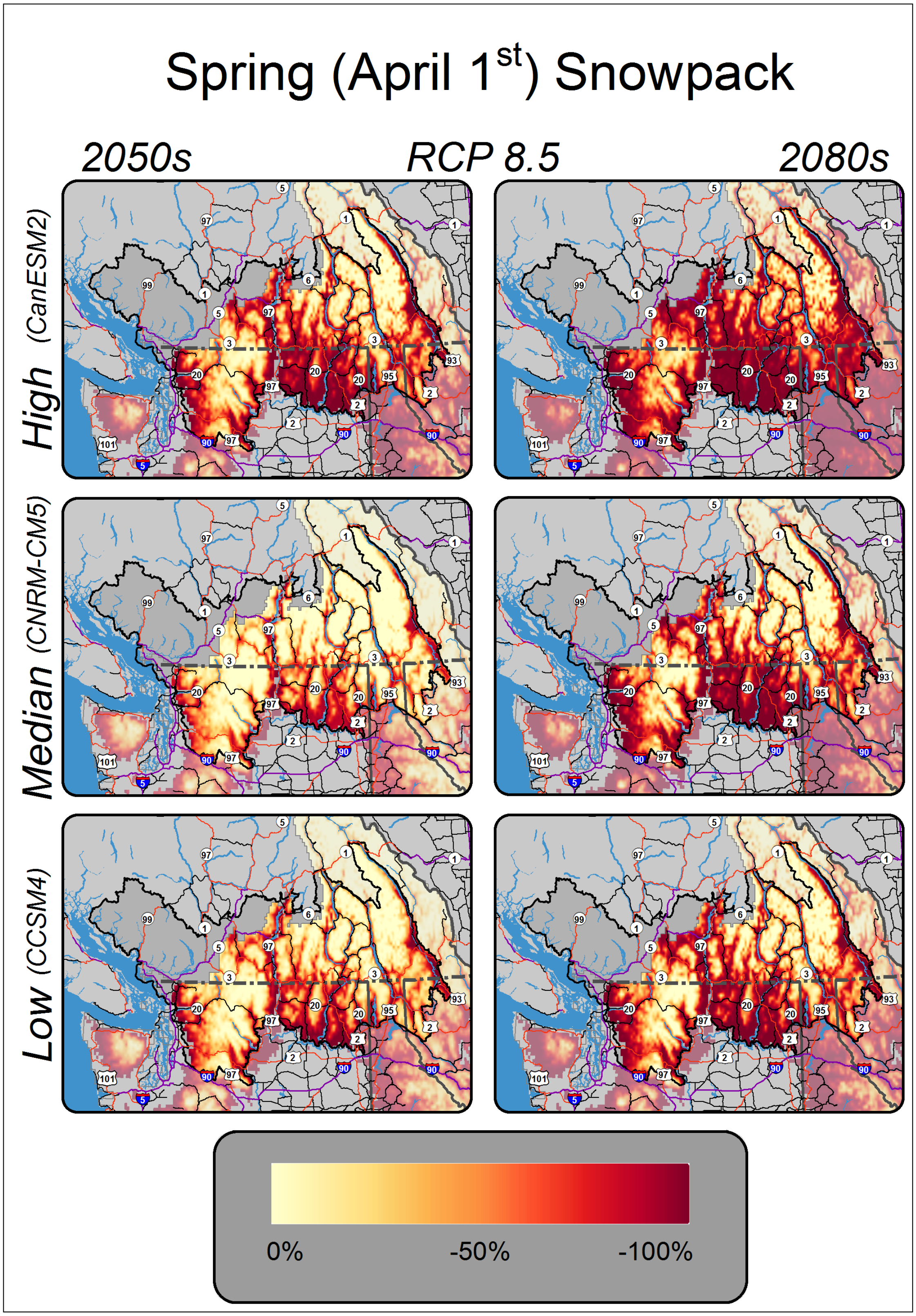
Appendix D.6a. Spring (April 1st) Snowpack

ii) Extent: Okanagan-Kettle Region



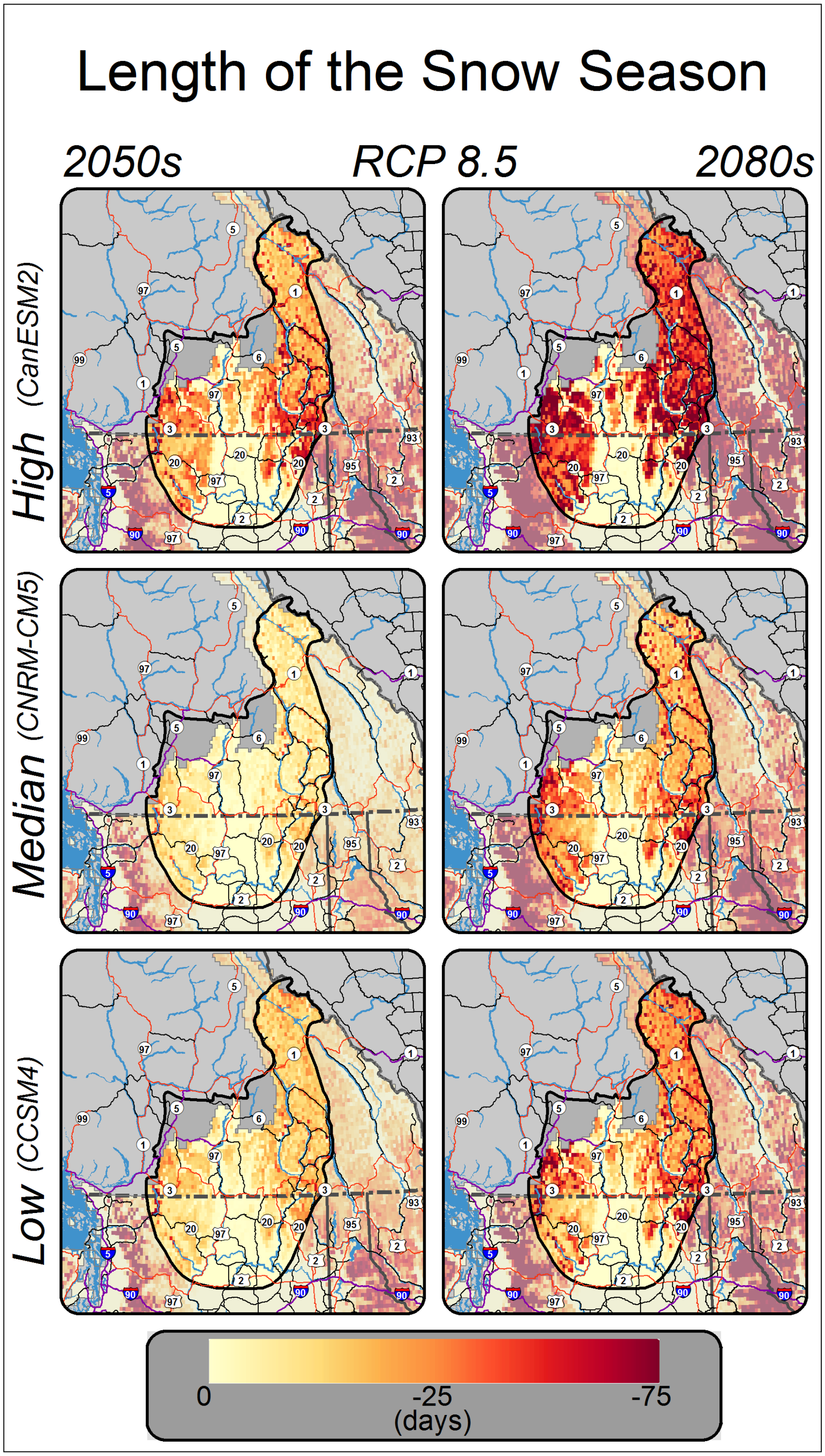
Appendix D.6a. Spring (April 1st) Snowpack

iii) Extent: Washington-British Columbia Transboundary Region



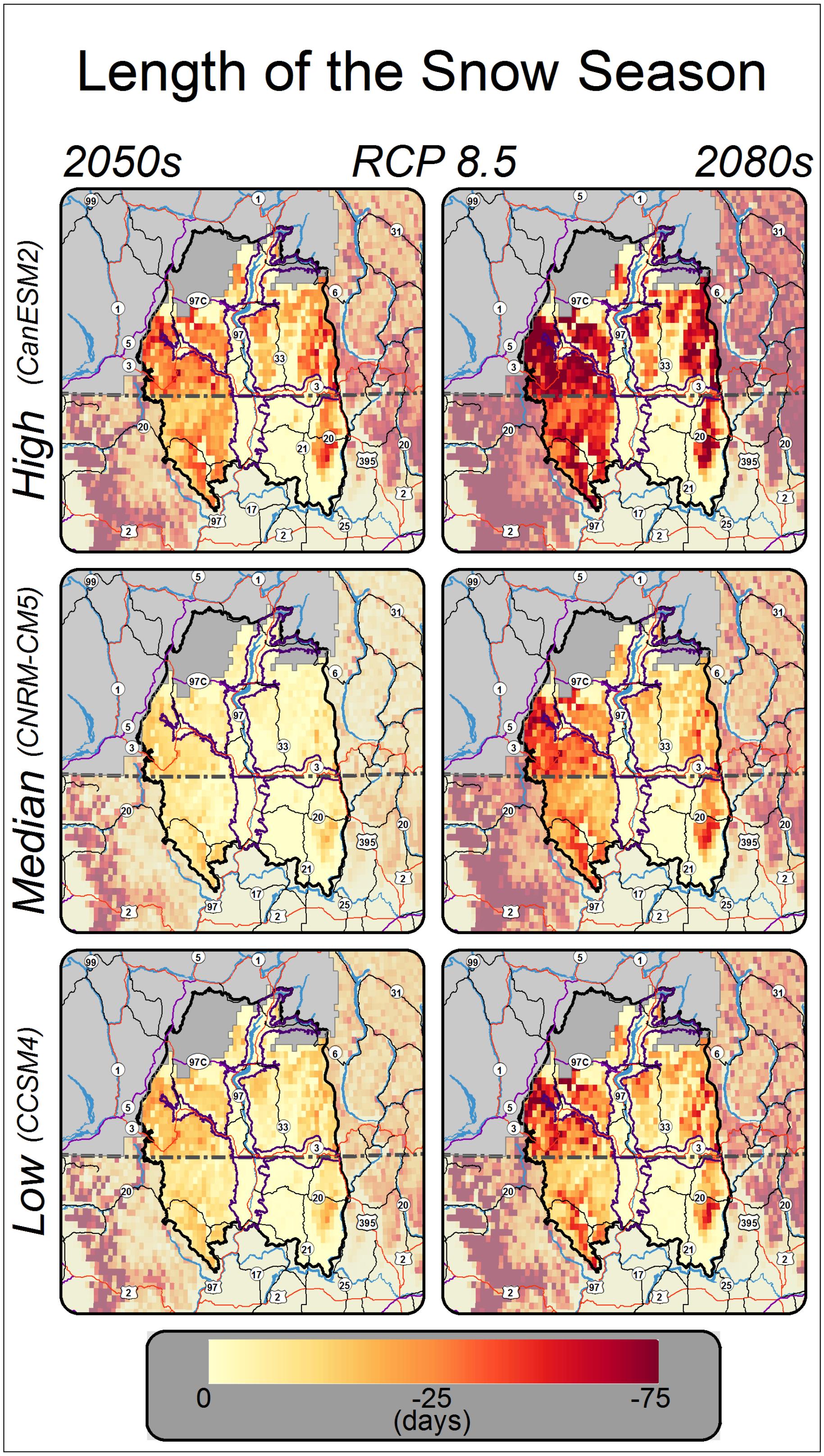
Appendix D.6b. Length of Snow Season

i) Extent: Okanagan Nation Territory



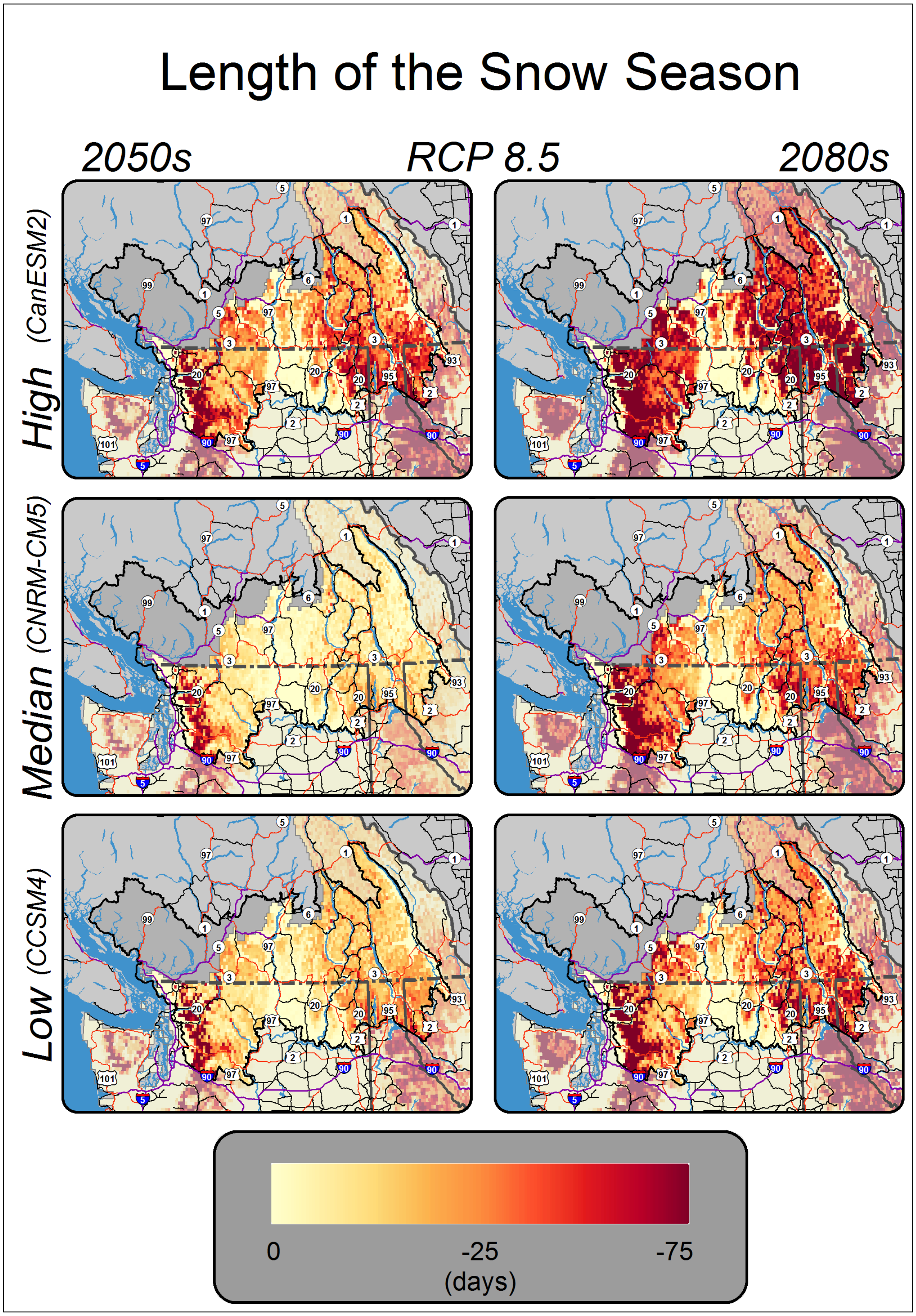
Appendix D.6b. Length of Snow Season

ii) Extent: Okanagan-Kettle Region



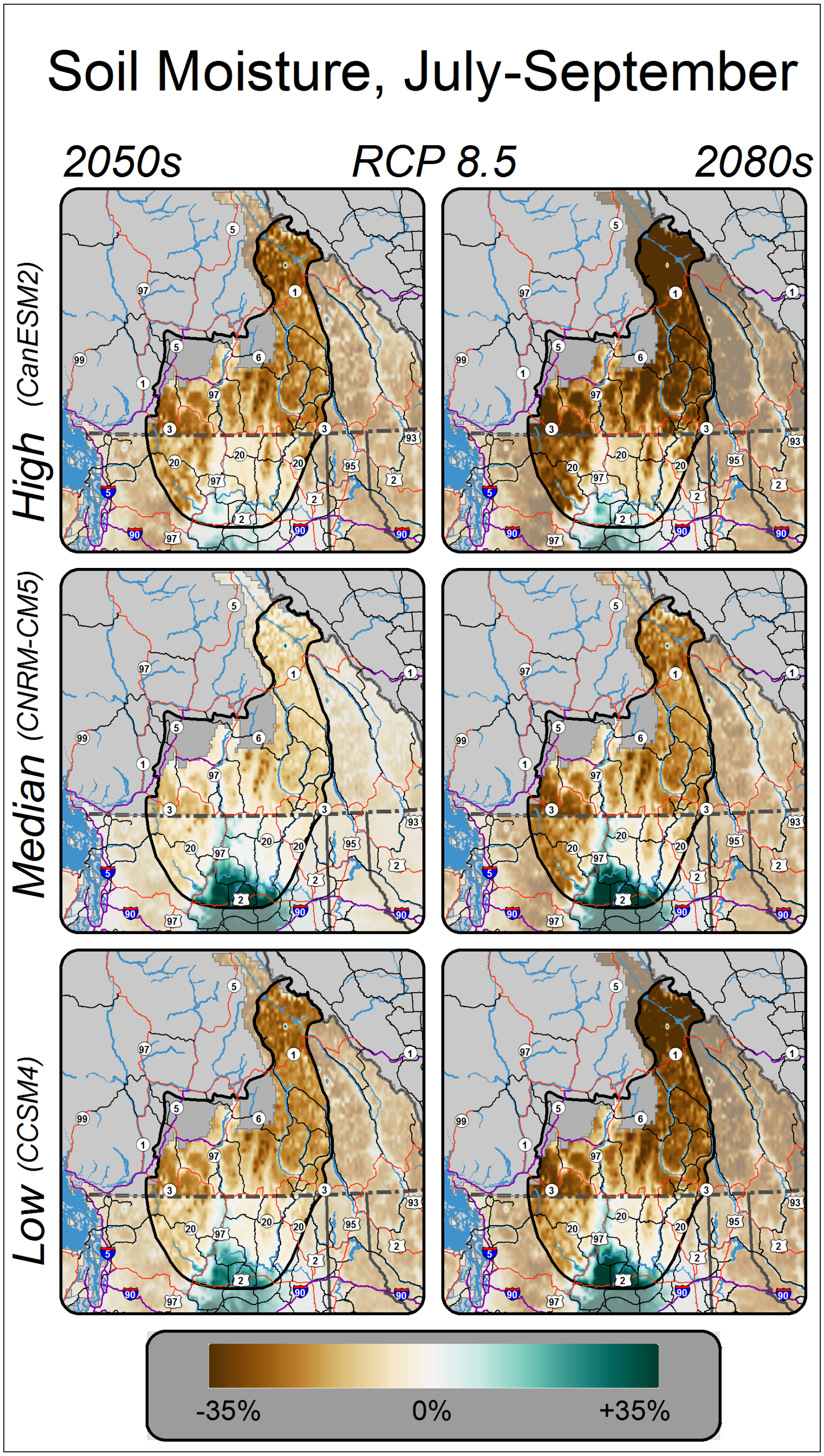
Appendix D.6b. Length of Snow Season

iii) Extent: Washington-British Columbia Transboundary Region



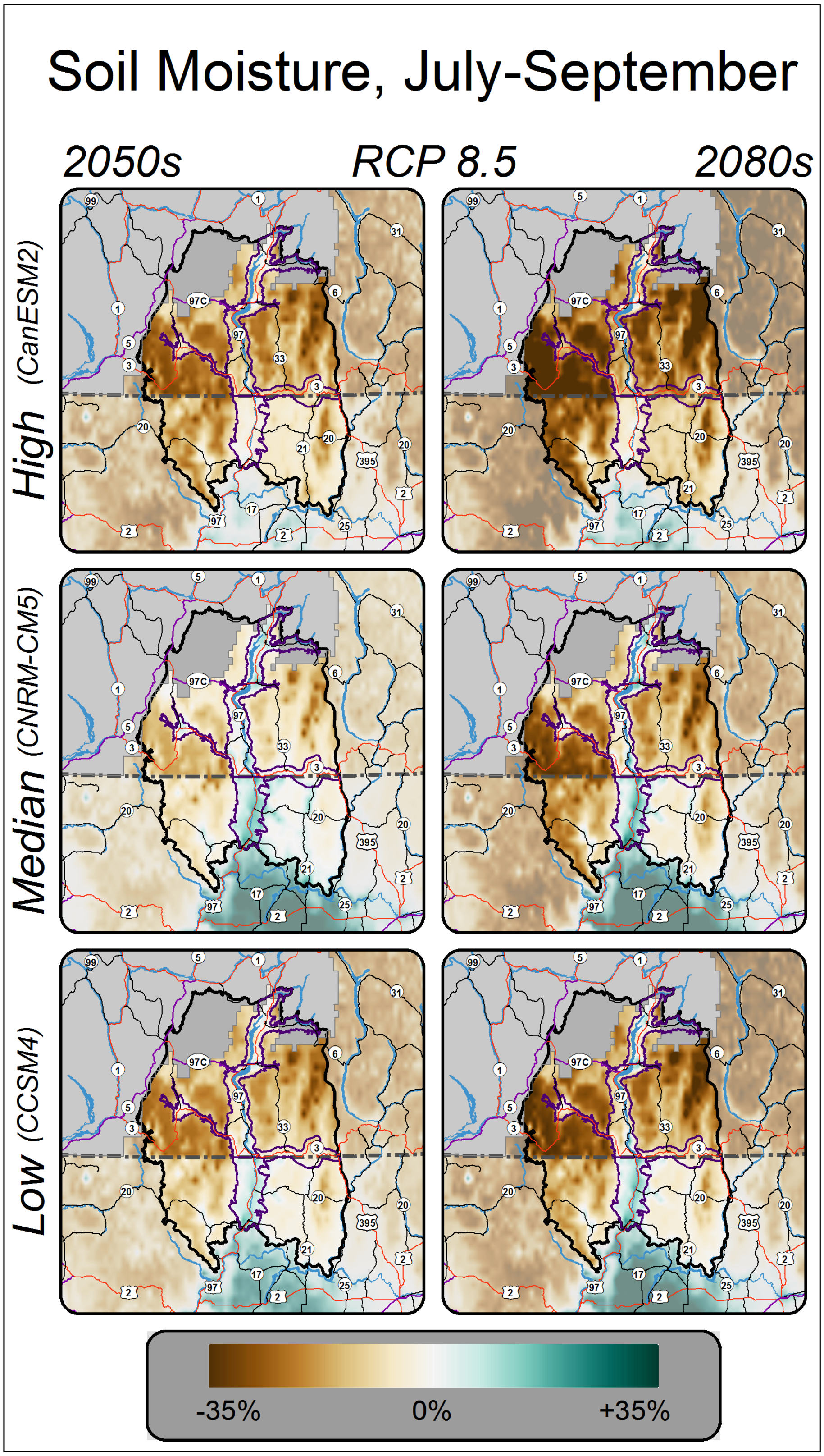
Appendix D.6c. Soil Moisture, July-September

i) Extent: Okanagan Nation Territory



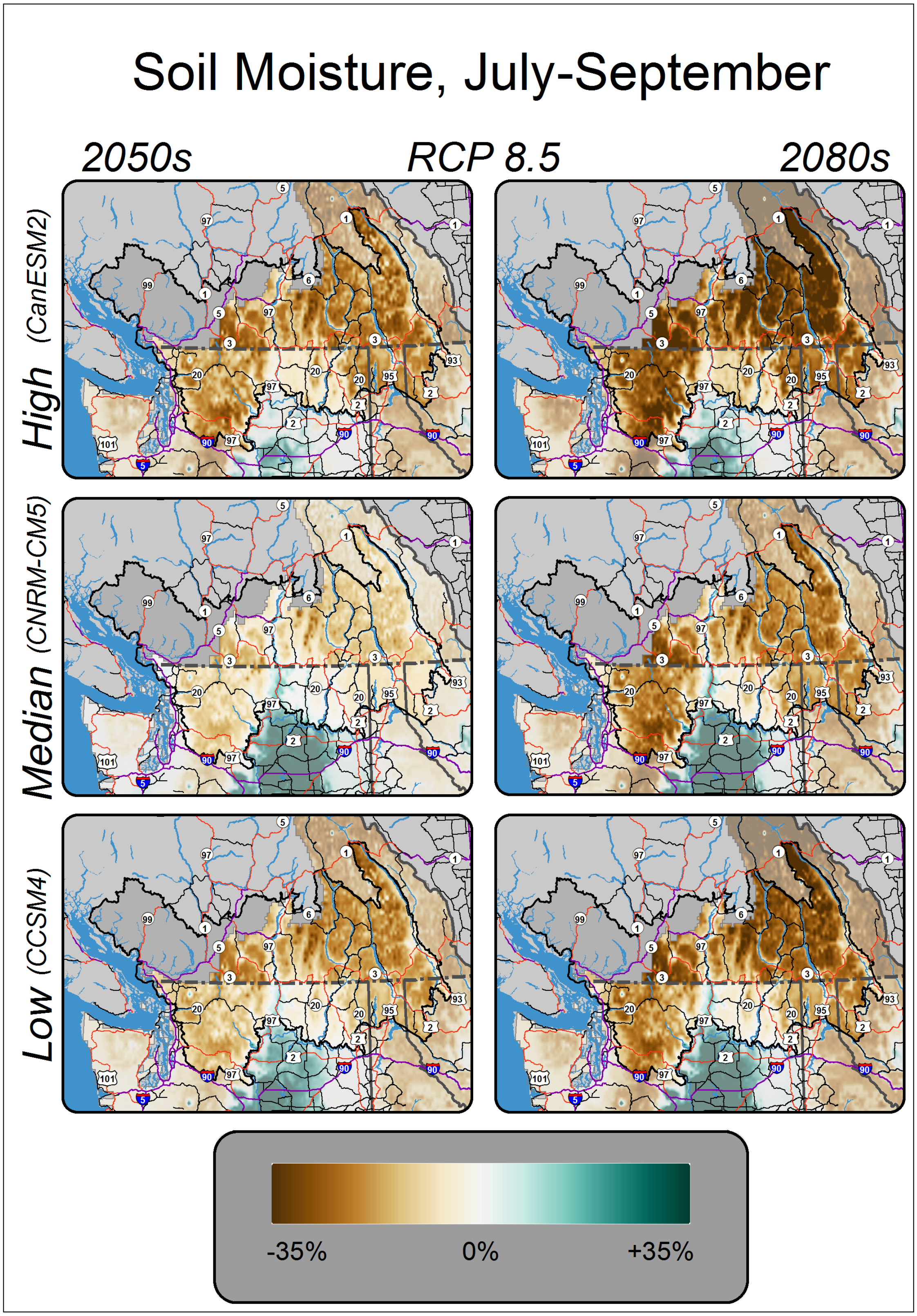
Appendix D.6c. Soil Moisture, July-September

ii) Extent: Okanagan-Kettle Region



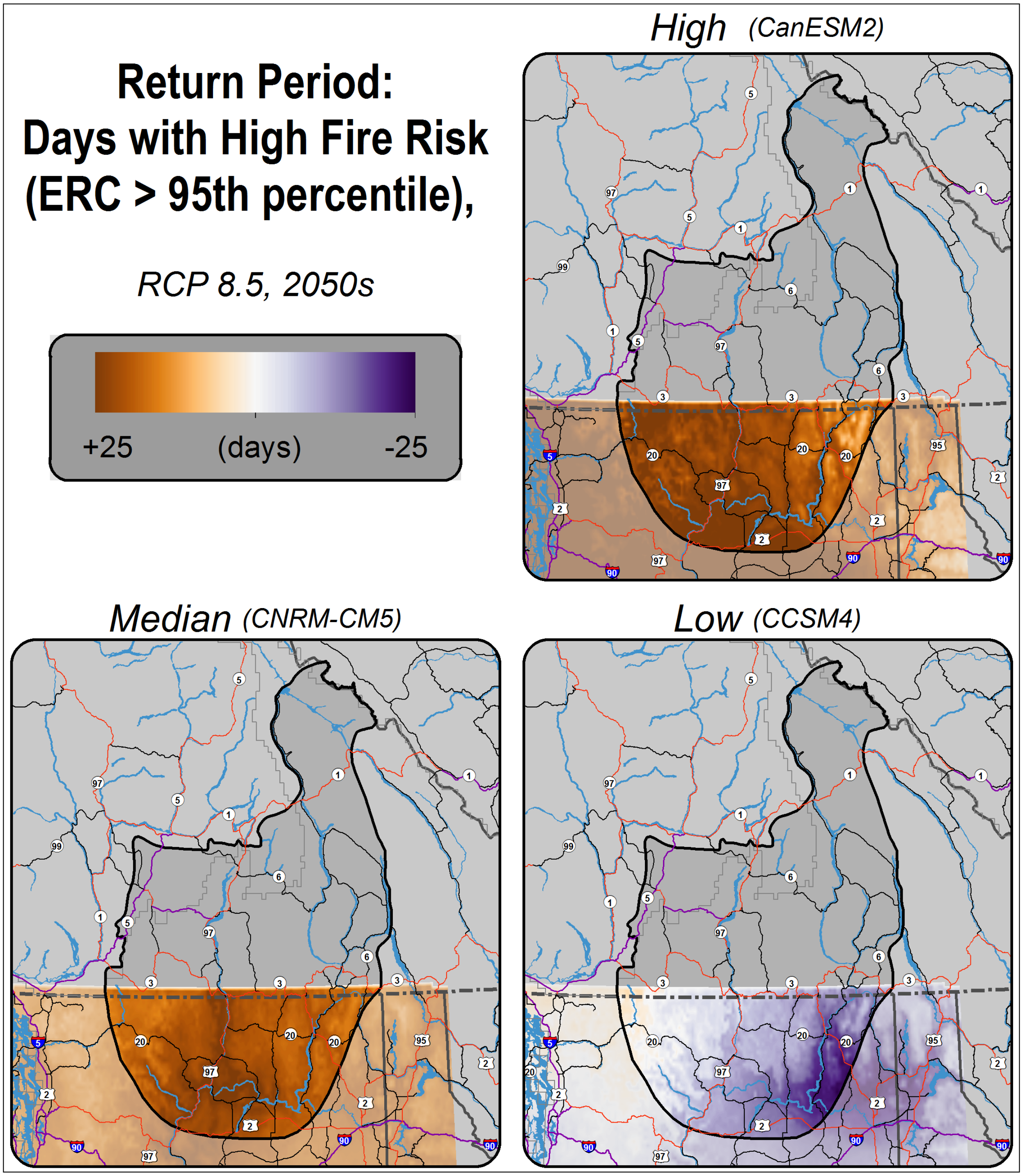
Appendix D.6c. Soil Moisture, July-September

iii) Extent: Washington-British Columbia Transboundary Region



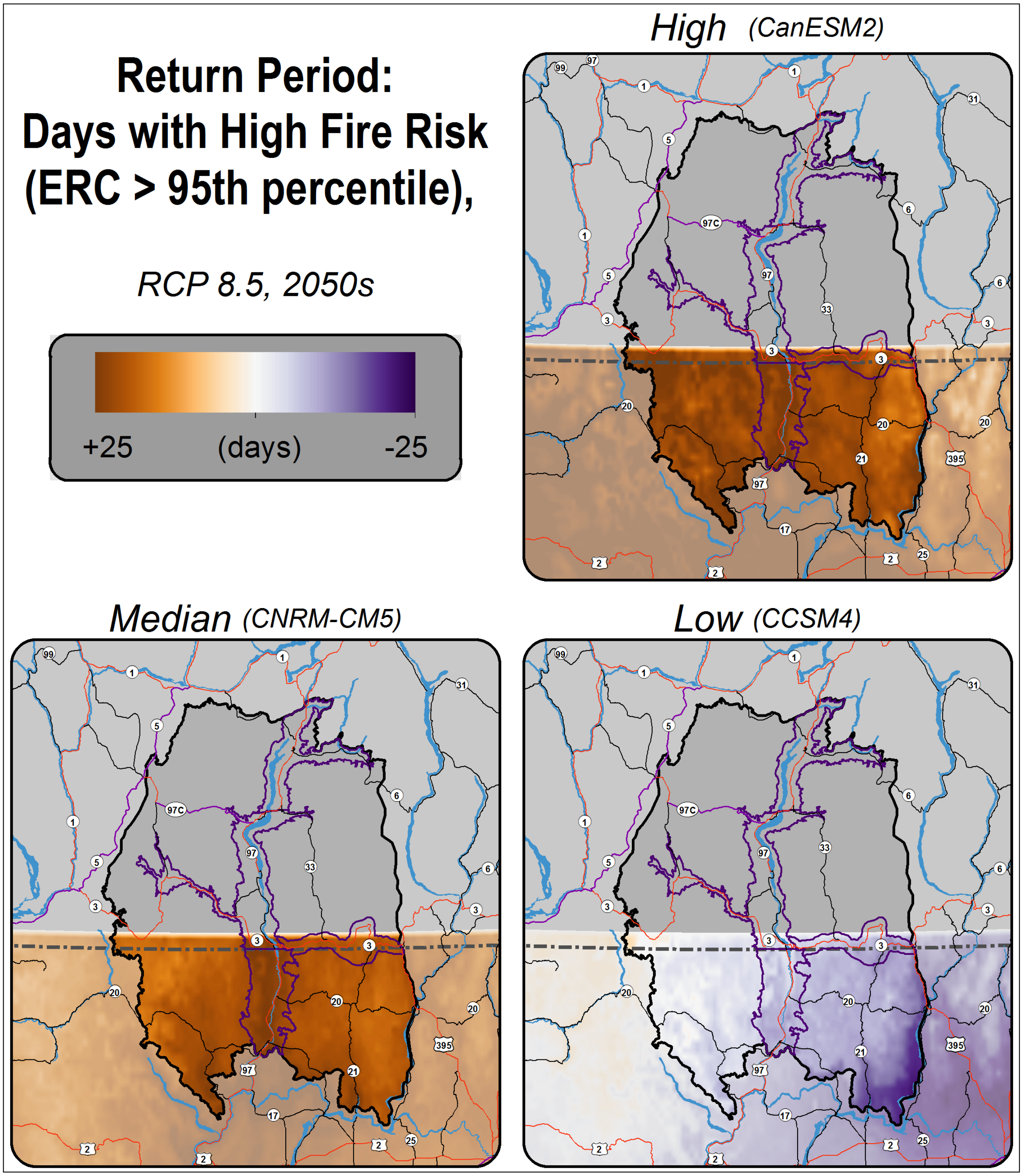
Appendix D.6d. Days with High Fire Risk

i) Extent: Okanagan Nation Territory



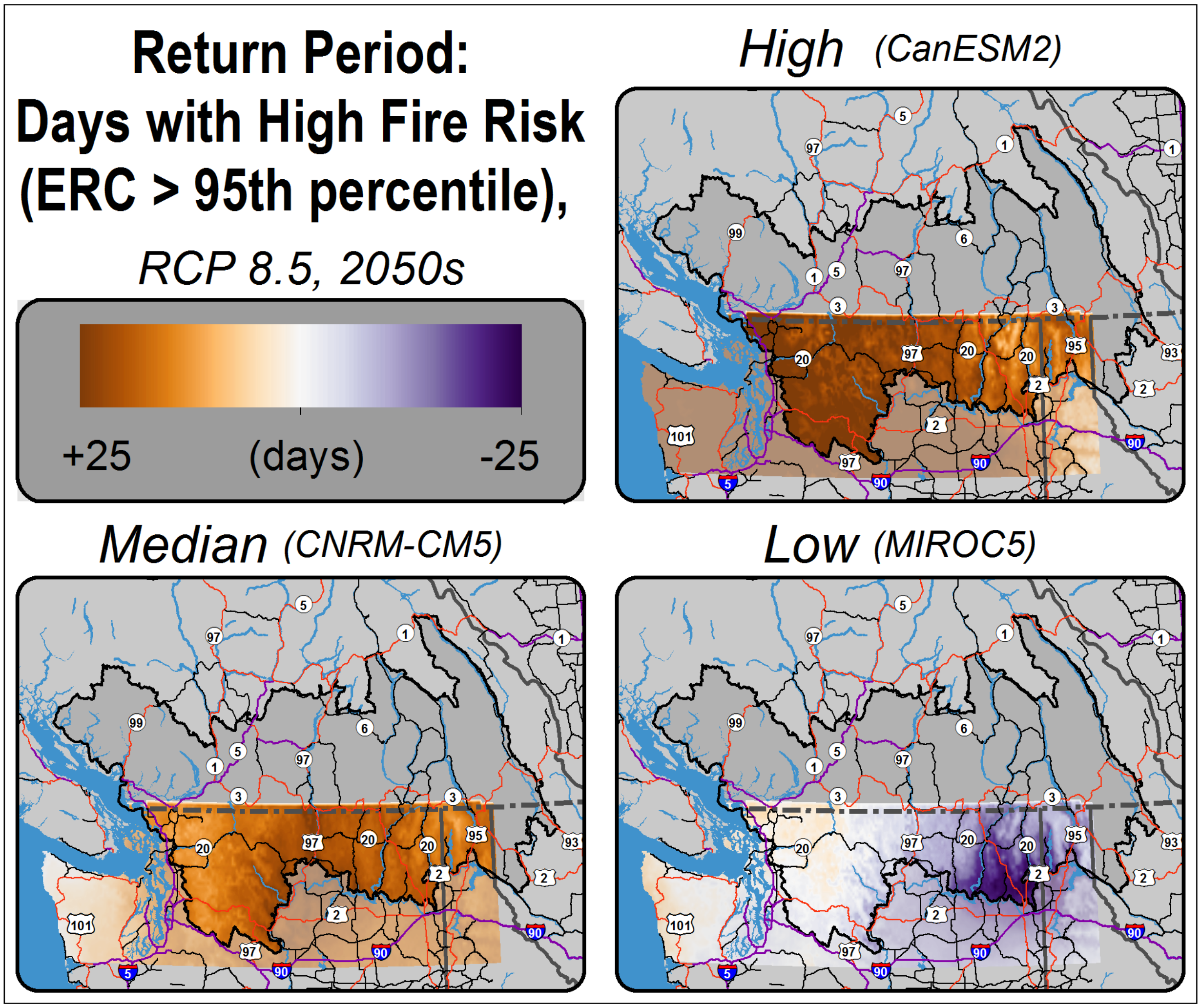
Appendix D.6d. Days with High Fire Risk

ii) Extent: Okanagan-Kettle Region



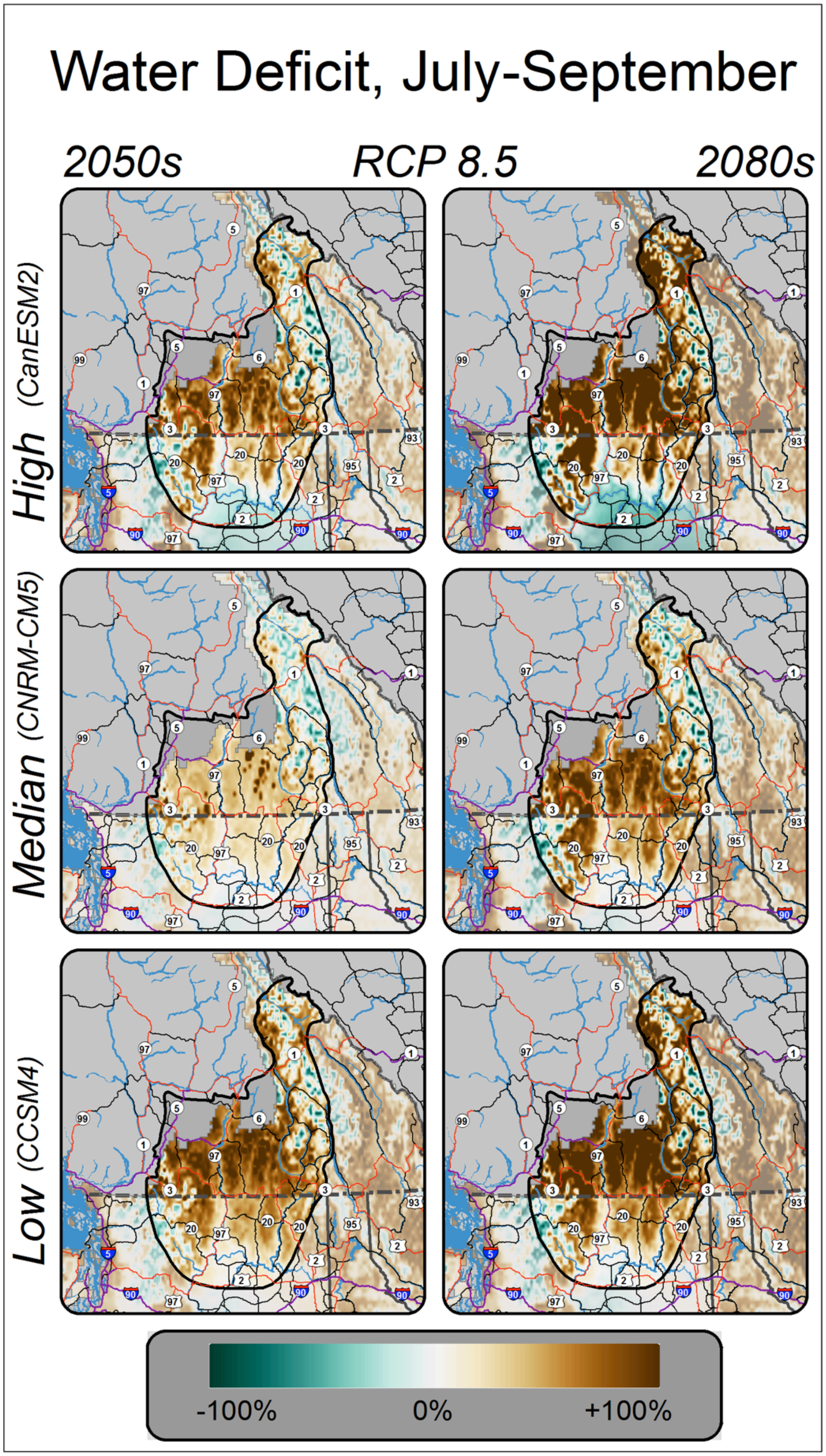
Appendix D.6d. Days with High Fire Risk

iii) Extent: Washington-British Columbia Transboundary Region



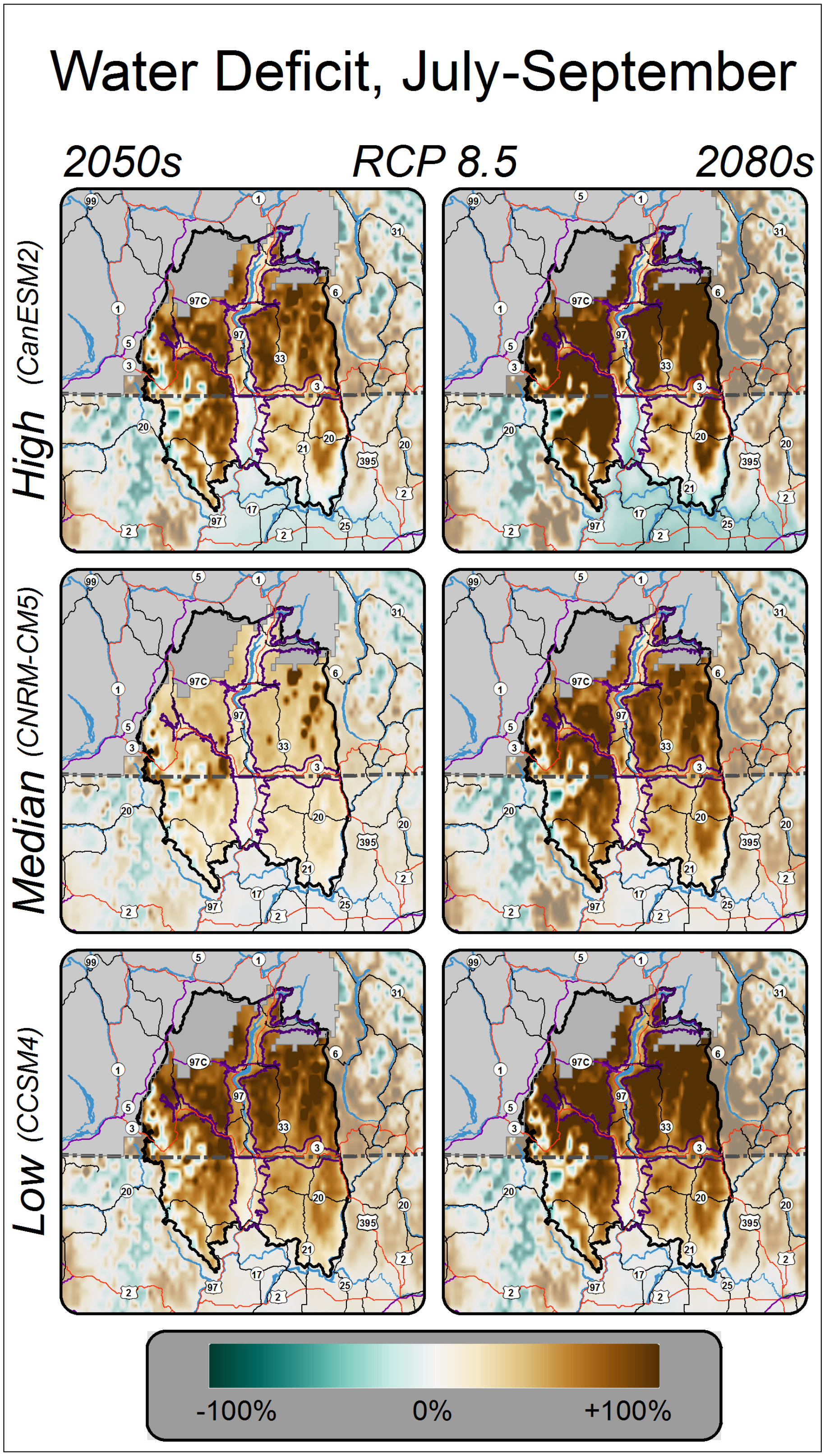
Appendix D.6e. Water Deficit, July-September

i) Extent: Okanagan Nation Territory



Appendix D.6e. Water Deficit, July-September

ii) Extent: Okanagan-Kettle Region



Appendix D.6e. Water Deficit, July-September

iii) Extent: Washington-British Columbia Transboundary Region